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Introducing Two New Weed Control Tools: A "Smart" Spray Wand and a Wildland Weed Treatment Time Model

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INTRODUCING TWO NEW WEED CONTROL TOOLS:

A “SMART” SPRAY WAND AND A WILDLAND

WEED TREATMENT TIME MODEL

by

Bryan E. Dayton

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ABSTRACT

Introducing Two New Weed Control Tools: A “Smart” Spray Wand and a Wildland Weed Treatment Time Model

by

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Utah State University, 2015

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Department: Plants, Soil, and Climate

Millions are spent managing invasive weeds on public lands each year. Wildland invasive weed treatment bids are based primarily on acreage or hours but can be influenced by variables that increase treatment time and cost. Often neither the agency contracting the treatment nor the contractor has a clear idea of the amount of time that will be involved based on these variables. This makes it difficult to develop an accurate budget or bid for invasive weed control projects. It also limits managers in seeking funding and justifying treatment costs.

A model has been developed that can predict herbicide application time due to four variables, weed canopy cover, slope, land cover, and weed visibility. Other variables were explored.

The “smart” spray wand (SSW) is a new precision tool used to develop this model. The SSW is a spray wand with an integrated GPS and a flow meter for use with any type of spray system. The wand records the GPS location, herbicide flow, application time, and associated data of each treatment spray point. This information provided necessary data for the treatment time model. Weed control total treatment time (T_{Tot}) was hypothesized to include both treatment time (T_t) and rest time (R_t). The development and benefits of a wildland weed treatment time model are discussed.

An accurate treatment time model could 1) establish an accurate standard for contractors and land managers, 2) assist in planning and managing limited treatment resources, and 3) justify funding requests and expenditures.

The primary influence of the model is due to weed canopy cover ($p=<2.2e-16$, $R^2=0.5607$), with smaller impacts by other variables. If canopy cover, slope, land cover, and weed visibility information can be obtained for a weed control project, the model can be used.

(96 pages)

PUBLIC ABSTRACT

Introducing Two New Weed Control Tools: A "Smart" Spray Wand
and a Wildland Weed Treatment Time Model

Bryan E. Dayton

Wildland invasive weed treatment, a primary task of land managers, is expensive. Variables including weed canopy cover, slope, land cover, and weed visibility can affect treatment time and cost. A partnership was established with the Department of Plants, Soils, and Climate at Utah State University, Providia Management Group (PMG Environmental LLC) and Jardyne Technologies to develop a wildland weed treatment time model to better understand the effect of these variables on treatment time.

The "smart" spray wand (SSW) is a new precision tool used to develop this model. The SSW is a spray wand with an integrated GPS and a flow meter that can be used with any type of spray system. The wand records the GPS location, herbicide flow, application time, and associated data of each treatment spray point, and provided necessary data for the development of the treatment time model.

The weed canopy cover had the largest impact on treatment time. If canopy cover, slope, land cover, and weed visibility information can be obtained for a weed control project, the new model can be used to estimate treatment time and therefor cost. An accurate treatment time model could 1) establish an accurate weed control cost standard for contractors and land managers, 2) assist in planning and managing limited treatment resources, and 3) justify weed control funding requests and expenditures.

ACKNOWLEDGMENTS

Thanks to Scott Pratt, owner of PMG Environmental LLC (PMG) and Jardyne Technologies, and developer of the SSW, for providing the financial support and equipment for this project. His vision to create a weed-free world, his creativity, and his courage to jump into even the most daunting task has provided the fuel and tools for this project. Fieldwork treating weeds/gathering data was enjoyable primarily because of all of the great staff at PMG Environmental. Thanks!

Thanks to my major professor, Ralph Whitesides, for his willingness and interest to collaborate with PMG, for his enthusiasm, encouragement, and assistance through the whole project. My appreciation extends to my research committee, Corey Ransom, Chris Call, Bruce Miller, DeeVon Bailey, Grant Cardon, Doug Ramsey, and Eric Thacker, for their time, counsel and enthusiasm in this project. Thanks to personable and exceptional professors at Utah State University in the Plants, Soils, and Climate; Watershed and Wildland Sciences; Applied Economic; Biology; and Statistics departments. Thanks to Keren Williams, the senior staff assistant, for cheerfully navigating my hoops of funding, university requirements, and dissertation defense. Thanks to Xin Dai, my statistics consultant, for many inspiring hours in R translation.

I am grateful to my Grandpa and Grandma Munk for their educational encouragement: To Grandpa for teaching me that a bachelor degree is just a “warm-up,” and to Grandma for valuing higher education enough to put all of her brothers through college. Thanks to my mother and father who taught me discipline and that “I can do hard things.” Thanks to family and friends who have been patient when I missed fishing, camping, and travel trips while working on my dissertation. Thanks to my good wife, Minnie, and my children, for their great academic examples, love, and support.

Thanks especially to God, for the matchless gift of His Son; for a strong body and mind, academic opportunity, and joy in scientific discovery; and for His peace and innumerable miracles that have brought me to this point.

Bryan E. Dayton

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CHAPTER 1

INTRODUCTION

Extent of Invasive Weeds

Invasive weeds cost billions of dollars per year in decreased productivity and control costs. On public lands they reduce recreational use, decrease plant and animal diversity, threaten endangered species with competition and destroy animal habitat (Pimentel et al. 2005) .

Weed management on wildland, wilderness, non-agriculture, and steep or rough terrains can be especially difficult due to inaccessibility. These areas may have mixed forbs that it make it difficult to treat without damaging native plants, and can necessitate backpack spot treatment (Figure 1-1).

Figure 1-1. Wildland areas may necessitate backpack spot weed treatment such as this dyers woad (*Isatis tinctoria*) area with steep mountainous cliffs and scrub oak (*Quercus gambelii*) land cover.

In 2009, Federal land management agencies spent $1.563 billion for invasive species control on only a fraction (3.2%) of the known acres infested on public lands. With the estimation that weed populations expand 12 to 16 percent annually and with current tools, there is little hope that this weed invasion can be controlled (Beck 2013). Due to the large economic and environmental impact of invasive weeds, weed control is a primary concern and task of land managers, but most land managers agree that they are underfunded in weed control (Beck 2013; Kettenring & Adams 2011). With limited funding, smarter tools are needed to make progress to manage weeds. This dissertation introduces two new tools in weed management; the "Smart" spray wand and a weed treatment time model, and discusses their possible benefits.

The "Smart" Spray Wand

Benefits of Precision Agriculture. Precision agriculture (PA) includes a wide range of farming application equipment, mapping tools, and displays. These tools can provide multiple benefits to farm management. With PA, differential application of herbicides, pesticides and fertilizer can be made in varied environments. PA has simplified much of its inventory work by using GIS software and associated equipment to map the spatial distribution of fertilizer, pesticides and herbicide application. This PA inventory can quickly provide information for improved management decisions. It can also reduce pollution due to excess herbicide and fertilizer use, and can be used for planning multi-year management (Khosla et al. 2008; Robert 2002; Stull et al. 2004). A has developed a standard that can be followed for wildland weed treatment.

Precision Equipment for Non-Agriculture Weed Treatment. Precision equipment is beginning to be developed for non-agriculture weed treatment. For example, the “smart” spray wand (SSW, patent pending, Figure 1-2), currently being developed under the “SprayTrax” trade name, system has been developed is currently being tested. The SSW is a spray wand with an integrated GPS and a flow meter that can be attached to any type of spray system including a backpack sprayer, truck or UTV/ATV sprayer. The SSW records the applicators travel each second and the GPS location, herbicide flow, application time and associated data of each spray point (Figure 1-3). Associated data may include site information, weed species, applicator, herbicide used, weather data or other information (Table 1-1). The SSW includes a display and toggle button to select the applicator, job, and weed species. It has quick weed species select buttons to quickly change between common weed species during treatment. It has a flow meter and MicroSD™ card port for data storage and transfer (Figure 1-4). Data from the SSW can be used by the wildland manager in the same way information from PA is used by the farmer.

Figure 1-2. The “smart” spray wand (SSW) is a new precision tool that records the applicators travel each second and the GPS location, herbicide flow, application time and associated data of each spray point.

Table 1-1. SSW data capture included location, herbicide flow, application time and associated data of each spray point.

WAND	FLOW	ELEV (ft.)	DATETIME	PLANTID
1305	0.0021560	6211.94	5/30/13 9:08:07	garlic mustard
1305	0.0006300	6209.65	5/30/13 9:08:08	garlic mustard
1305	0.0020000	6208.33	5/30/13 9:08:09	garlic mustard
1305	0.0019520	6208.99	5/30/13 9:08:10	garlic mustard
1305	0.0000000	6208.99	5/30/13 9:08:11	hoary cress
1305	0.0000000	6208.01	5/30/13 9:08:12	hoary cress

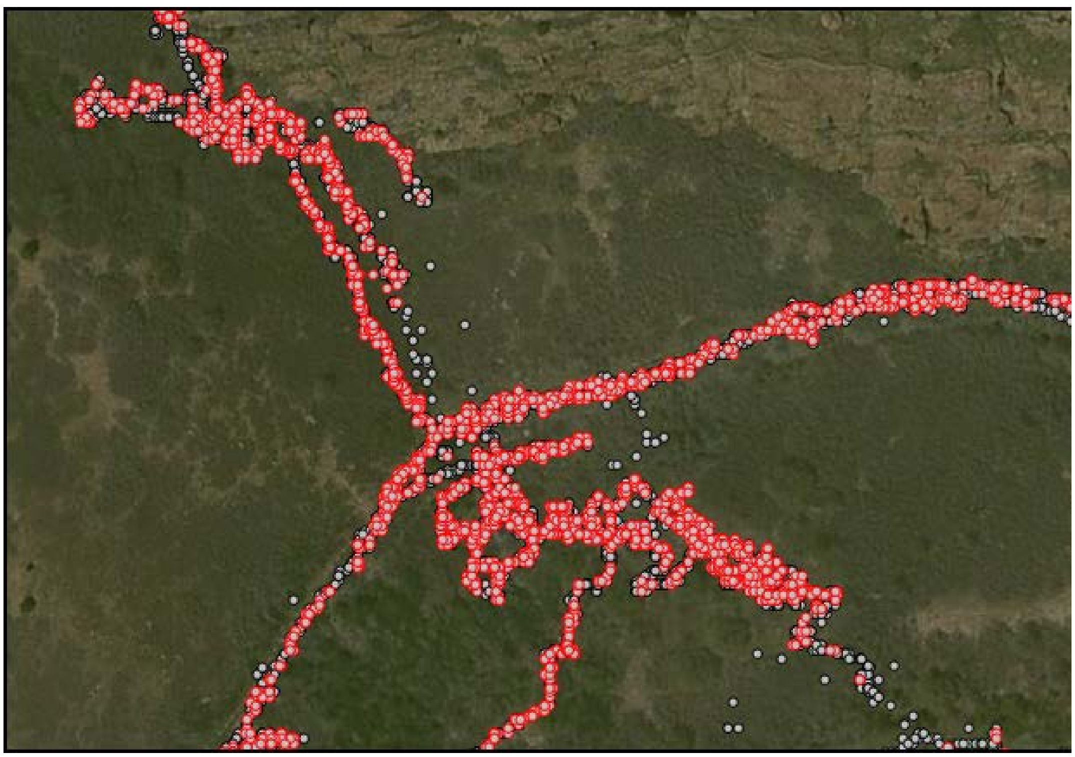

Figure 1-3. SSW mapped data sample. The SSW records the applicators travel each second (black points) and the GPS location, herbicide flow, application time and associated data of each spray point (red points).

Figure 1-4. The SSW schematics include a display and toggle button to select the applicator, job and weed species. It has quick weed species select buttons to quickly change between common weed species during treatment. It also includes a flow meter and MicroSD™ card port for data storage and transfer.

The “smart” spray wand can improve overall weed control by: 1) saving inventory time and money, 2) increasing ecological, treatment, and funding accountability, 3) justifying funding requests; 4) streamlining data flow for cooperative management; 5) Increasing information for planning and management; and 6) expanding research possibilities in wildland weed control. This dissertation is an example of expanded research with the SSW. The SSW’s ability to collect data has allowed for the development of a wildland treatment time calculation model.

Introducing a Treatment Time Model

Developing a Treatment Time Standard. When budgeting for weed control in wildland areas, often neither the organization/agency contracting the weed control effort nor the contractor has a clear idea of the time and costs involved. This can lead to poor or incomplete treatment. For example, herbicide treatment bids for wildlands are often requested based on acreage (Beck 2013; Kadramas et al. 2003) without taking into account other variables that may increase treatment time and cost. This places the liability on the contractor who loses money if the job is not accurately budgeted and the treatment time exceeds the estimate. It may also be detrimental to the contracting entity due to a contractor providing quick and less thorough treatment to completely “treat” the area with the funds allotted. Treatment bids may also be let based on a per hour basis. There is currently no standard for treatment area per hour. A standard could assist in communicating and justifying expectations, but a treatment time model has not previously been developed.

Foot Travel Models

Models that address foot travel over varied slopes and land cover have been developed in logging, military travel, emergency rescue, hiking (Braun 2008; Kondo & Seino 2010; Langmuir 1984; Tobler 1993) and other exercises (Minetti et al. 2002). These models can be useful in some approximations of movement in weed control, but are not accurate because they do not account for weed canopy cover and weed visibility.

An accurate treatment time model could 1) establish an accurate standard for contractors and land managers, 2) assist in planning and managing limited treatment resources, and 3) justify funding requests and expenditures.

CHAPTER 2

THE “SMART” SPRAY WAND (SSW)

Development of the SSW

In the spring of 2006, Providia Management Group Environmental LLC (PMG) began providing invasive weed control to public and private organizations. PMG’s clients required increased accountability of weed treatment. This prompted PMG to increase accountability of its applicators which provided treatment detail that could be reported to PMG clients. To do this, PMG began using two commercially available tools, the Ag Leader® GIS spray display and mapping program (InSight Field Display and SMS Advanced, Ames, Iowa, USA) for ATV/UTV boom treatment data collection, and hand held GIS (Archer® Field PC, Juniper Systems, Logan, Utah, USA) for backpack treatment data collection. The AgLeader® equipment had the advantage of recording and creating a map of flow and herbicide use. It had a trail system that mapped and displayed areas treated and paths traveled in real time. With this tool, PMG was able to account to clients for the UTV weed boom treatment.   The AgLeader® mapping system, however, was limited to weed treatment where a UTV could travel and to a boom or half boom pattern. An extended hose could be attached to spot treat low density weed areas or to access difficult off trail treatment areas, but the resulting map did not account accurately for the actual treatment location (the spray end of the hose), because the AgLeader® GIS was located on the UTV/ATV and not on the spray wand. In low weed density areas the boom was often excessive, and in areas with mixed forbs the boom was not practical because of high native plant damage.

Much of the work that PMG did was within environmentally sensitive areas that required spot treatment. These areas benefited by high accountability of herbicide use and long term follow up with at a high mapping accuracy. The hand held GIS (Archer®) mapped weed treatment of an applicator on foot, at the end of the hose or with a backpack sprayer, but it did not record the flow in association with weed points. To resolve this, PMG attached processors with flow meters to herbicide backpacks. A backpack computer was connected to the hand-held Archer® GPS via BlueTooth® (Kirkland, Washington, USA). This recorded flow data associated location data for flow points as weeds were treated. This increased the accuracy of treatment accountability with backpack treatment, but the bulky backpack with attached computer had to be worn when using a hose and reel from a truck or UTV if flow was to be recorded.

To resolve this, in the Fall of 2012 Scott Pratt, owner of PMG, created a research and development company (Jardyne Technologies) and developed the “Smart” spray wand (SSW). The SSW is an integrated GPS and flow meter that could be attached to any type of a spray wand or gun. This provided flow, GIS and other input data as desired, such as applicator, treatment site and herbicide used. It also could allow the applicator to record and change quickly between weed species (Figure 2-1).

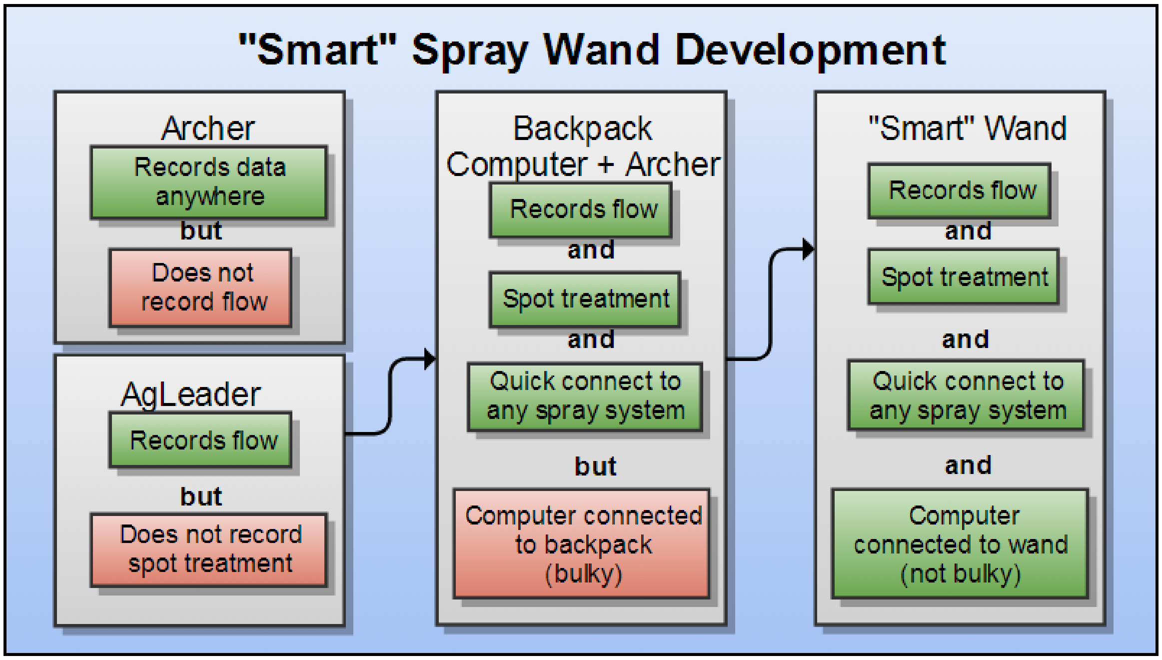

Figure 2-1. “Smart” spray wand (SSW) development history. The development objectives were spray equipment that would record flow and GIS point data, connect to any spray system, and be easily carried.

Improved Management with the SSW

Creating Weed Inventories. Technology development has increased options to inventory weeds and to record and communicate this information. Current inventory tools include modeling, imaging and hand mapping. Modeling utilizes GIS layers to predict where weeds may currently be and the potential spread. This is done with the use of GIS tools and layers to model the association of weed environment niches with terrains, soils, climate and other layers (Jarnevich et al. 2010). Imaging is used to visualize and map weed areas using satellite or airborne imagery. Hand mapping is done by technicians on site gathering GIS data of weed locations, canopy cover, species and other information.

Following mapping, a treatment plan is developed. If funding is justified and obtained, then treatment is done. After treatment the inventory may be re-done to determine the success of treatment and account for resources spent. Modeling and imaging may be useful in initial prediction and identifying weed populations, but may not be as useful in monitoring following treatment. Hand mapping may be the primary tool for follow-up inventory. If follow-up treatment is needed, treatment is repeated; followed by inventory. This process is repeated until the weed infestation is controlled or treatment funds are no longer available. Repeating the inventory and herbicide application is essential to effective treatment (Dewey & Andersen 2004; Ransom et al. 2012)**,** but long-term follow-up can be extremely expensive and may be difficult to justify**.** Managers may wonder how infestations can be monitored more efficiently.

Create Precise Inventories While Saving Time and Money. When using the SSW for multi-season weed treatment, each time treatment is done an inventory is created. Like precision agriculture, it can simplify much of the inventory work by combining mapping with application. This can eliminate or reduce the cost for follow-up monitoring. As the SSW records herbicide flow data it can create a precise map (Figure 2-2). The canopy cover can be estimated by dividing herbicide flow by calibrated gallons per acre. With SSW use, population changes can be calculated yearly, and newly discovered infestations can be treated and mapped (Figure 2-2). In Figure 2-3, the 2013 and 2014 treatment shows the change in weed species populations after treatment. The hoary cress (*Cardaria draba*) and hounds tongue (*Cynoglossum officinale*) canopy cover decreased following treatment in 2013. Canopy cover changes can be quantified by comparing the herbicide flow in the area each year.

Figure 2-2. Recording weed species and herbicide flow with the SSW. Canopy cover can be estimated by dividing herbicide flow by calibrated gallons per acre.

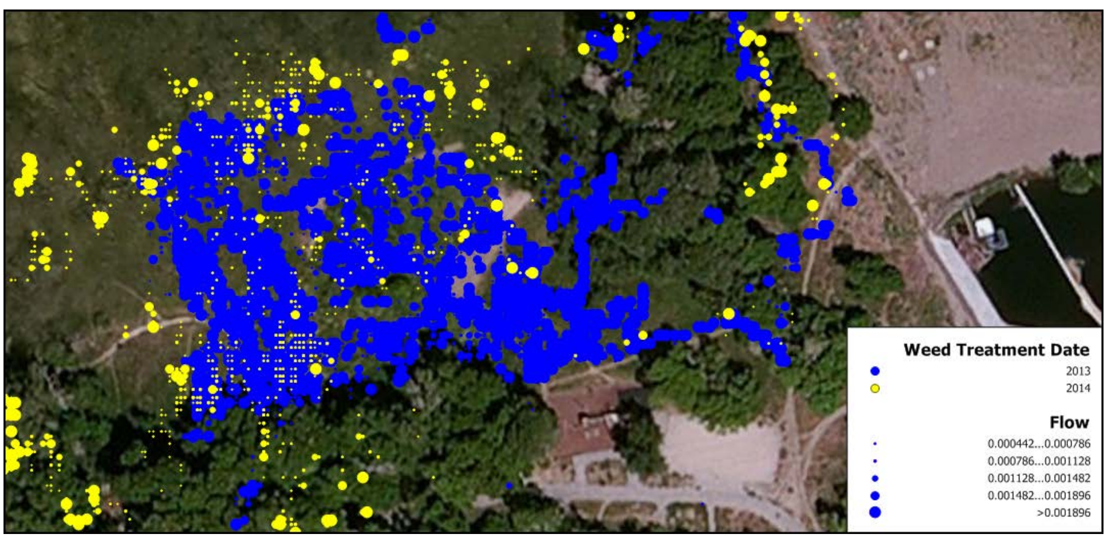

Figure 2-3. Weed canopy cover change from 2013 and 2014. SSW treatment accounted for weed treatment canopy cover decrease from 2013 to 2014 in primary hoary cress area (blue points). In 2014, new weed infestations were found outside of the primary area (yellow points).

Ecological Accountability. SSW use may simplify and increase ecological accountability to the client, the public and regulatory agencies. This is especially beneficial in sensitive areas such as water or endangered species locations. For example, Figures 2-3 and 2-4 show non-compliance to a 100 ft (30 meter) buffer to water bodies. The weed treatment was less than 60 ft (20 meters) from the dam on the right side of map.

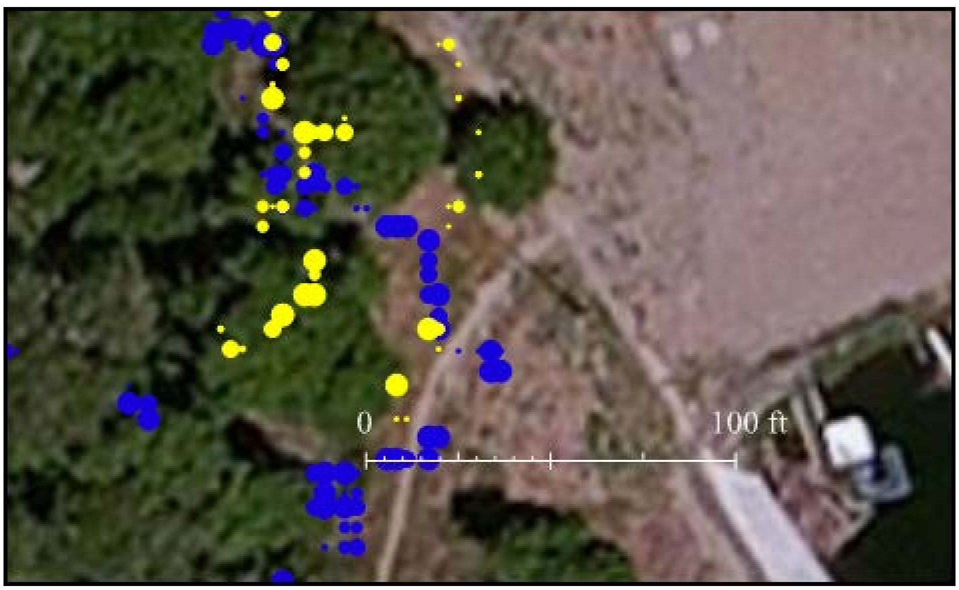

Figure 2-4. SSW treatment accounts for applicator compliance in sensitive areas. Map shows non-compliance to a 100 ft (30 meter) buffer to water bodies (from Fig. 2-3).

Another example of the SSW's ability to account for regulatory compliance is found in Figure 2-5. The backpacks were calibrated at 24 gallons per acre, but delivered 29 gallons on this 0.85 acre area (34 gal/treated acre), a 42% herbicide excess.

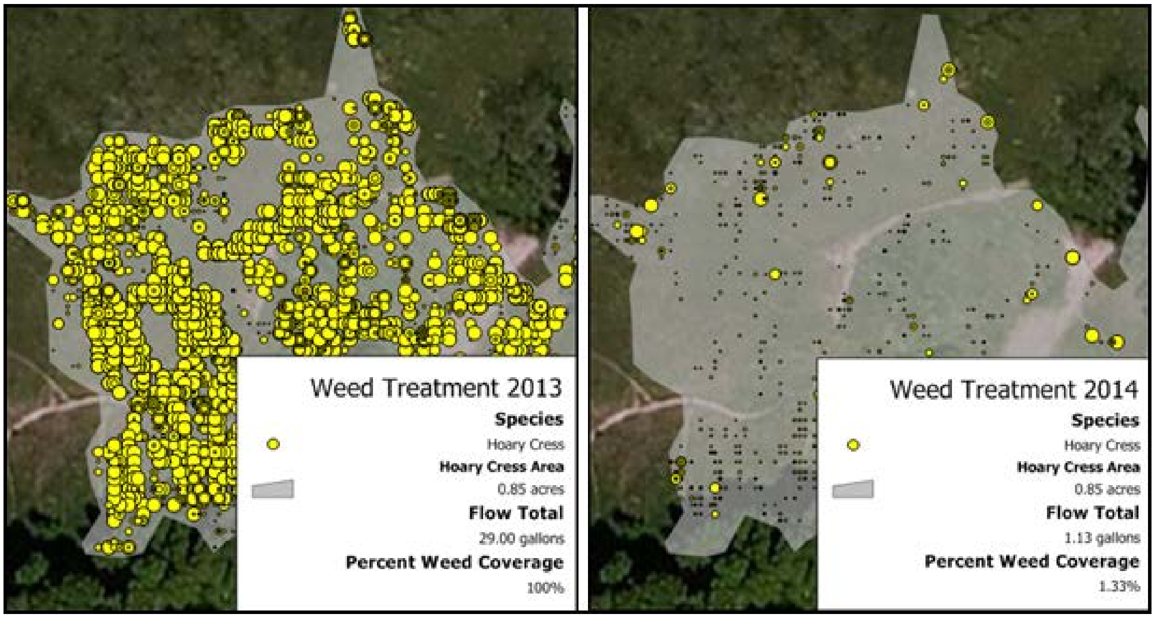

Figure 2-5. Weed population change and herbicide compliance in 2013 and in 2014. Based on flow, a hoary cress population decrease from 100% to 1.33% could be reported. The 2013 map shows non-compliant herbicide application per acre. The backpacks were calibrated at 24 gallons per acre, but put down 29 gallons on this 0.85 acre area (34 gal/treated acre), a 42% herbicide excess.

Funding Justification and Accountability. Multiple year use of the SSW can show the extent of weed population decrease due to weed control efforts (Figure 2-5). This data may justifies treatment and simplify accountability to funding sources. With population changes recorded yearly, weed control effectiveness can be evaluated and reported. For example, the 2013 and 2014 treatment in Figure 2-5 shows the change in weed species populations after treatment. The canopy cover changes can be quantified and reported by comparing the herbicide flow in the area each year. In this example based on herbicide flow, a hoary cress population decrease from 100% to 1.33% could be reported.

Treatment Accountability. There may be times when the treatment effectiveness of an application is called into question. For example, PMG contracted to treat a site and guaranteed to the client a 90% kill. On completion, the client still saw weeds, was not happy and did not want to pay for the application. PMG walked through the area of concern with the client, counted the weeds that were not dead and compared that number with the SSW treatment points. The kill count exceeded 90%. The information was presented to the client, and the client was impressed and happy to pay for the treatment (S. Pratt, personal communication, June 2011).

Cooperative Management. County, state, and national efforts have been made to create weed web sites to communicate locations of weed populations. These web sites can involve key players and communities in monitoring and controlling weeds. The public can record GPS locations and send them to weed supervisors. SSW data capture could add to this effort by streamlining the creation and sharing of infestation maps. The SSW and other similar data acquisition tools can add to the accuracy and ease of transfer to weed web sites for public education and cooperative management.

Improve Planning and Managing Weed Control. The inventory or mapping plays an important role in weed management by identifying the problem, providing baseline data, bringing public awareness and justifying funding (Fremont County Weed and Pest n.d.). However, inventory may not generally be a priority. For example, in 2008 it was estimated that less than 5% of the Montana weed control budget was used for inventory (Montana Noxious Weed Summit Advisory Council Weed Management Task Force [MNWSACWMTF] 2008). This may limit weed location and extent information for management decisions. Dewey stated, “one of the most basic mistakes made by some weed managers [is to] attempt to control weed invasions without first determining the identity, distribution, or relative abundance of the invaders." He went on to describe that this kind of an approach is like a doctor treating an illness or injury before a diagnosis, or search and rescue before gathering facts and maps (Dewey & Andersen 2004).

Following an initial inventory, weed treatment with the SSW can provide a high precision inventory during treatment. It can assist managers in planning and managing weed control, and in seeking and justifying funding. It can improve overall weed control by automatically monitoring herbicide and applicator effectiveness over multiple treatment seasons.

Uses of SSW for Research. Historically, as new tools have been developed, our ability to measure and understand the world expands. Use of tools like the SSW may assist us in understanding weed population changes in response to treatment, or developing better models for weed control. For example, the SSW records point flow data in conjunction with geospatial data during weed treatment. From this data weed canopy cover can be mapped and associated with recorded slope, land cover resistance and treatment time. This information has allowed for the development of a weed treatment time model.

CHAPTER 3

WILDLAND WEED TREATMENT TIME MODEL

Introduction

Backpack herbicide treatments are done on varied wildland environment areas. These treatment areas can include varying weed canopy cover, slope, land cover and weed visibility (Figure 3-1). Weed visibility is the distance at which weeds can be identified (Andersen 2007). Slope is the measure of the steepness of an area. Land cover is the physical material on the surface of the earth, including grass, trees, water etc. (Food and Agriculture Organization of the United Nations n.d.). Weed canopy cover is the percent weeds per area and is usually based on percent canopy coverage (Forest Service n.d.; North American Weed Management Association 2002).

Figure 3-1. Treatment areas with varying weed canopy cover, slope, and land cover. Dyers woad (*Isatis tinctoria*) treatment areas on wildland areas: dense dyers woad, on no slope, high visibility (0.5 miles, 0.8 km) with a low resistance land cover of meadow grass (left), and an area with moderate weed canopy cover, high slope, moderate visibility (100 feet, 30 meters) and a high resistance land cover of thick scrub oak (right).

Wildland invasive weed treatment bids are based primarily on acreage or hours but can be influenced by variables such as weed canopy cover, slope, land cover and weed visibility that influence treatment time and cost.

Often neither the agency contracting the treatment nor the contractor has a clear idea of the amount of time treatment will take depending on these variables. This makes it difficult to develop an accurate budget or bid for invasive weed control projects. It also limits managers in seeking funding and justifying treatment costs.

Benefits of a Treatment Time Model

Increase Spending Efficiency. An accurate treatment time model could establish a standard for contractors and land managers. For example, in Beck's (2013) testimony to the House Natural Resources Committee, he stated that there were $305 million federal treatment dollars uncategorized which was likely due to spending more per acre than necessary due in part to high labor expenses. This type of inefficiency could be improved with a standard from a treatment time model.

Establish a Treatment Cost Standard. A clear understanding about the costs associated with weed treatment can improve the partnership between land managers and contractors. A treatment time standard can reduce problems in the bid process. It can establish a baseline of fiscal and treatment expectation. The treatment time standard can assist land managers in prioritizing, planning and managing limited treatment resources.

Justify Funding. A treatment time standard can justify funding requests and expenditures. It can more acurately predict costs of current treament vs future treament of infestations that have expanded over time (Kadramas et al. 2003). The treatment time model could more accurately estimate the cost of weed spread by taking into account varied weed canopy cover, slopes, land covers and weed visibility. For example, for wildland spot treatments, it may be cheaper to control weeds at low canopy cover on more acres than to treat high canopy cover infestations on less acres. A treatment time model could explain those interactions.

Slope and Treatment Time

Weed control with backpacks can be executed, without climbing gear, on slopes up to approximately 50°. Models that address foot travel over varied slopes and land cover have been developed in many areas including military travel (Cesur 2005; Lee & Stucky 1998), archaeological modeling (Kondo & Seino 2010; Van Leusen 2002), hiking (Braun 2008; Langmuir 1984; Tobler 1993) and exercise physiology (Gomeñuka et al. 2014; Minetti et al. 2002). These models may provide a useful starting point for a weed control cost model, although they do not include variables such as weed canopy cover and visibility. In development of a backpack treatment cost model, slope was evaluated. Slope can influence treatment time in two ways: by increasing treatment area and by increasing resistance to the applicator.

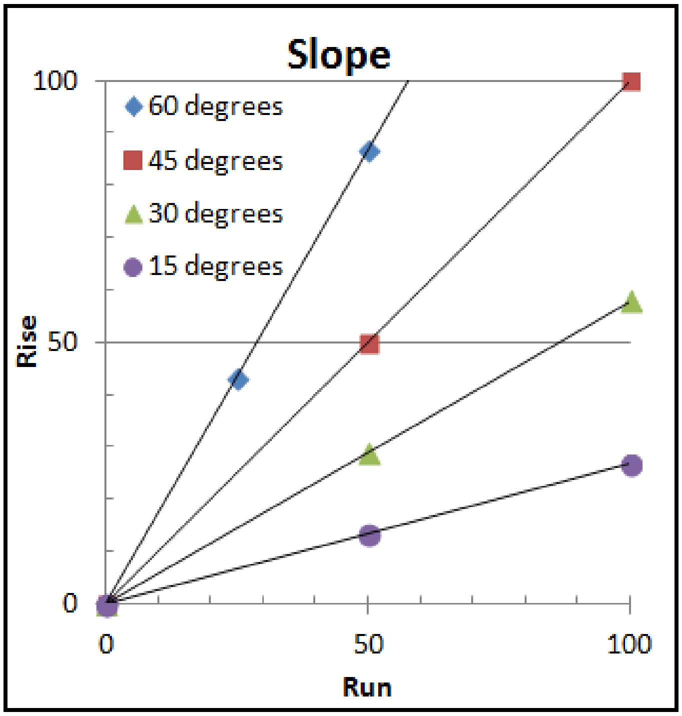

Figure 3-2. Slope (degree) examples. Weed control with backpacks can be executed, without climbing gear, on slopes up to approximately 50°.

Area Increases with Slope. Acreage is usually measured from a map or planar surface. Surface areas can be greater than map acres depending on the slope of the terrain (Anderson 1972). As slope increases the surface distance and therefore surface area increases (Figure 3-3). This increase can be substantial. For example, an area with a slope of 30° can increase the surface area compared to the map acreage by 20%). On an area with a slope of 50°, the surface area is increased by more than 50% (Figure 3-4).

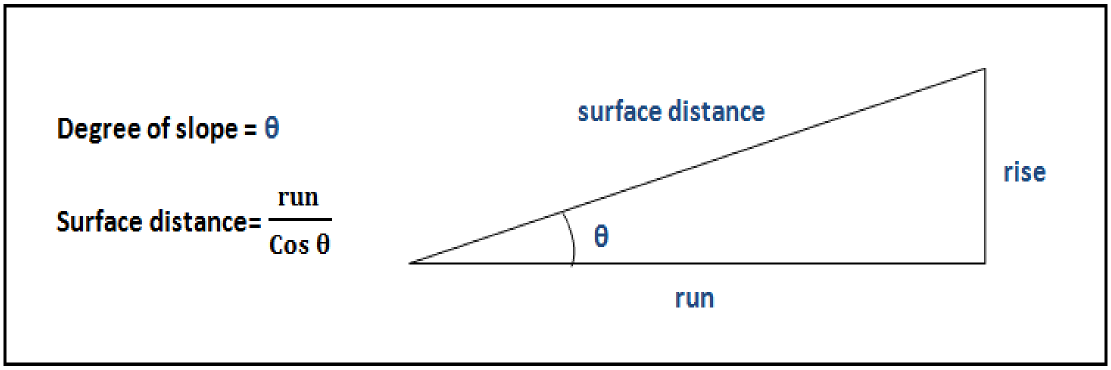

Figure 3-3. Surface distance increase with slope increase. As slope increases the surface distance and therefore surface area increases.

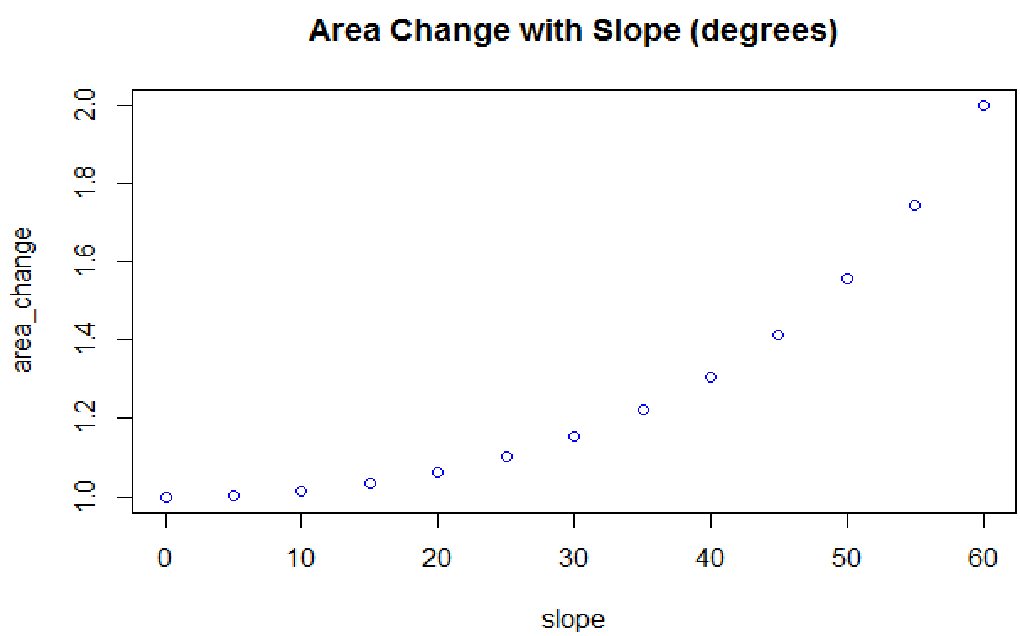

Figure 3-4. Surface area proportion increases as slope increases**.**

Increased Resistance to the Applicator with Increased Slope. As slope increases, maximum speed up the slope decreases due to increased energy costs and decreasing gait efficiency (Gomeñuka et al. 2014; Minetti et al. 2002).

Walking Models. W.W. Naismith, a founder of the Scottish Mountaineering Club in 1892, established hiking time estimation referred to as “Naismith’s Rule.” The rule states that a hiker can travel at 3.1 mph (5 km/hr) plus 1 hour per each 2000 ft (600 meter) ascent. Adjustments to Naismith rule were later made by Langmuir to account for downhill travel. Langmuir suggested subtracting 10 minutes for every 1000 ft (300 meters) of decent on easy slopes (>5 and <12°) and add 10 minutes for every 1000 ft (300 meters) of descent for steeper slopes (>12°) (Langmuir 1984). Others have suggested that Naismith’s rule was too optimistic and adding 25 or 50 % to the time would be more accurate (Braun 2008). More recently models have been developed using GPS and GIS.

Slope was shown to be a significant factor in travel speed and energy expended (Kondo & Seino 2010; Tobler 1993). Research has also been done to explore physiological energy costs of walking on varied slopes. Soule and Goldman (1972) developed a model to explain energy costs of movement through varied land covers. Later, Goldman worked with others to adapt that model to including slope and other variables (Pandolf et al. 1977). Since then Goldman’s model and other energy models have been widely used and adapted (Gomeñuka et al. 2014; Jobe & White 2009; Minetti et al. 2002; White & Barber 2012).

Vertical and Non-Vertical Movement on Slope. Slope models were developed to evaluate the energy and speed effects of movement up or down a slope. Limited work has been done to evaluate the range of vertical to horizontal movement on slopes (Kondo & Seino 2010). For example, if an herbicide backpack operator hiked up and down a sloped area he would have vertical travel (rise). If he traveled horizontally across the same area, his vertical travel could be zero (Figure 3-5). To account for the possible variation of vertical and horizontal travel on areas of the same slope, vertical movement on a slope must be included in the model.

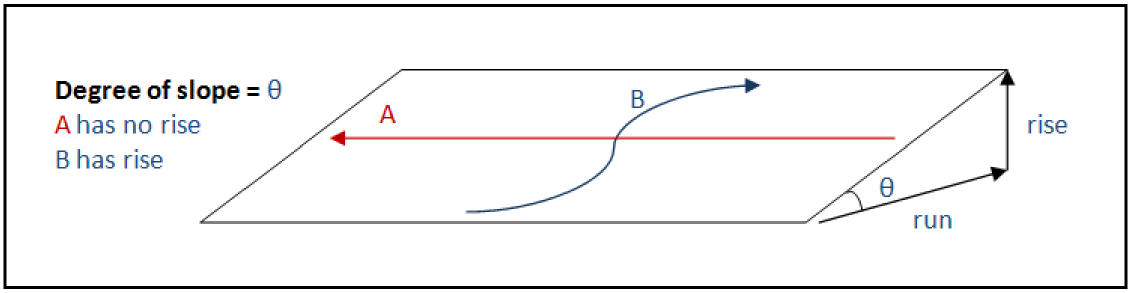

Figure 3-5. Horizontal versus vertical movement on a sloped area. **A** has no vertical movement (rise) whereas **B** does.

Weed Canopy Cover and Treatment Time

Weed canopy cover can influence treatment time in two ways: by slowing the applicator's forward movement and by decreasing swath widths. As the applicator approaches and identifies a weed he/she must slow or pause to treat the weed. This slows the applicator's forward movement and increases the treatment time. If there are several weeds within the applicator's reach, he/she must stop and treat all of the weeds within that reach before moving forward. In areas with close to 100% canopy cover, the applicator must move slowly as he swings the wand back and forth to treat the entire area. In these high canopy cover areas the applicator usually sprays with parallel swaths with a swath width limited to the applicators reach to cover the entire area. As swath width decreases, the number of swaths needed to cover the area increases. This increases treatment time.

Weed Prediction Models. A variety of models have been used to predict the possible presence or spread of weeds based on environmental or spatial factors (Gilham 2001; Lowry et al. 2007; Vanderhoof et al. 2009; Wadsworth et al. 2000). Modeling utilizes GIS layers to predict where weeds may be and where there is potential spread. This is done with the use of GIS tools and layers to model the association of weed environment niches with terrains, soils, climate and other layers (Jarnevich et al. 2010). These models can be very useful in decreasing the amount of area that must be mapped. This can save time and money especially when large tracts of lands are managed, but to know what is there, the area must be mapped.

Weed Mapping. Weed canopy cover is usually mapped based on percent canopy coverage (Forest Service, n.d.; North American Weed Management Association, 2002). The inventory or mapping plays an important role by defining the problem, providing baseline data, bringing public awareness and justifying funding (Fremont County Weed and Pest n.d.). However, inventory may not generally be a priority. For example, in 2008 it was estimated that less than 5% of the Montana weed control budget was used for inventory (MNWSACWMTF 2008). This may limit essential information such as weed location and weed canopy cover for management decisions. Dewey and Andersen (2004) reported that "one of the most basic mistakes made by some weed managers [is to] attempt to control weed invasions without first determining the identity, distribution, or relative abundance of the invaders." They compared it to a doctor treating an illness or injury before a diagnosis, or to rescue crews attempting a search and rescue mission before gathering facts and maps. Mapping is an essential starting point.

Following mapping, a treatment plan is developed. If funding is justified and obtained, then treatment is done. After treatment monitoring may be done to determine the success of treatment and to account for resources spent. If follow-up treatment is needed, treatment is repeated; followed by monitoring. This process is repeated until the weed infestation is controlled or eradicated. Repeating the monitoring and treatment is essential to effective management, but long term follow-up can be time consuming and expensive and may be difficult to justify to funding sources**.** How can this be done more efficiently?

Precision Equipment for Wildland Weed Mapping. Precision agriculture (PA) has simplified much of its inventory work by using geographical information systems (GIS) equipment to combine mapping with application. This automatic mapping can account for fertilizer, pesticides and herbicide use in a way that can quickly give feedback and provide information for decision making. There are a wide range of PA application equipment, mapping tools and displays.

Recently, precision equipment has been developed for non-agricultural weed treatment. The development of the SSW adds a new tool to the wildland weed control arsenal. The SSW can automatically eliminate the necessity of repeat mapping by recording flow data (records weed canopy cover and herbicides amount) and record species data during treatment. This can decrease costs, simplify accountability and make mapping more precise.

Efforts have been made to create county and state weed web sites to communicate locations of weed populations. These web sites can involve key players and communities in monitoring and controlling weeds. The SSW and other data acquisition tools can add to the accuracy and ease of transfer to weed web sites. They can also add to the accountability of herbicide use and the ease of follow up treatment monitoring. This can decrease weed control costs and assist in the overall control or eradication of noxious weeds. The SSW's ability to gather data has made it possible to develop a treatment time model. This model can predict herbicide application time due to weed canopy cover.

Land Cover and Treatment Time

Land cover is the physical material on the surface of the earth, including grass, trees, water, etc. (Food and Agriculture Organization of the United Nations n.d.). Land cover can influence treatment time in three ways: 1) by increasing resistance which slows the applicator; 2) by creating barriers to the applicator that must be walked around, thus increasing travel distance; and 3) by decreasing weed visibility so that narrower swaths must be walked to ensure weeds are identified.

Land Cover Increases Physical Resistance. High density land cover can cause physical resistance that slows the applicator and increases treatment time. Exploration of the physiological energy costs of waking on varied land covers has been evaluated and previously reported. Soule and Goldman (1972) developed a model to explain energetic cost coefficients for movement on paved road, dirt, light brush, heavy brush and swamp areas. Later, Goldman worked with others to include other variables in a model including slope, weight and load. (Pandolf et al. 1977). Following the Goldman work of 1972 and 1977 other energy models have been other energy models have been widely used and adapted (Gomeñuka et al. 2014; Jobe & White 2009; Minetti et al. 2002; White & Barber 2012). These models have been utilized and adapted for global information systems (GIS) least-cost path modeling. Least-cost modeling explores the relationship of land cover resistance to movement by diseases, plants, animals and humans (Epps et al. 2007; Spear et al. 2010).

Land Cover Affects Travel Distance. Some land cover can cause physical resistance that impedes or stops the applicator's movement. Examples of this are water bodies, wetlands, brush, trees, large rocks and areas with high slopes, including cliffs. The applicator must go around these objects. This increases treatment time, by increasing travel distance.

Land Cover Maps. Land cover can be determined by manual mapping or by satellite or fly over maps. Land cover maps have been developed including the nationwide USGS GAP land cover map (Lowry et al. 2007). These maps may provide land cover information in invasive weed treatment areas. With a treatment time model, land managers could utilize this land cover information to create accurate treatment time estimates.

Weed Visibility and Treatment Time

Weed visibility is the distance at which an individual can identify a weed (Andersen 2007). Weed visibility determines the effective detection distance (EDD), or the distance that a weed can be accurately identified. As visibility increases, search time decreases, which in turn decreases treatment time. The treatment time of an area is based on the travel speed and the swath width. The swath width is the distance weeds can be effectively detected on either side of the applicator as the swath is walked. The effective detection swath width (EDSW) is the distance at which weeds can be effectively identified on either side of the applicator as he/she walks a swath, and is 2 times the EDD (Andersen 2007) (Figure). If weeds are highly visible an EDSW can be large. If weeds are not very visible, the EDSW must be small to ensure that the applicator walks within a close enough distance to identify the weeds.

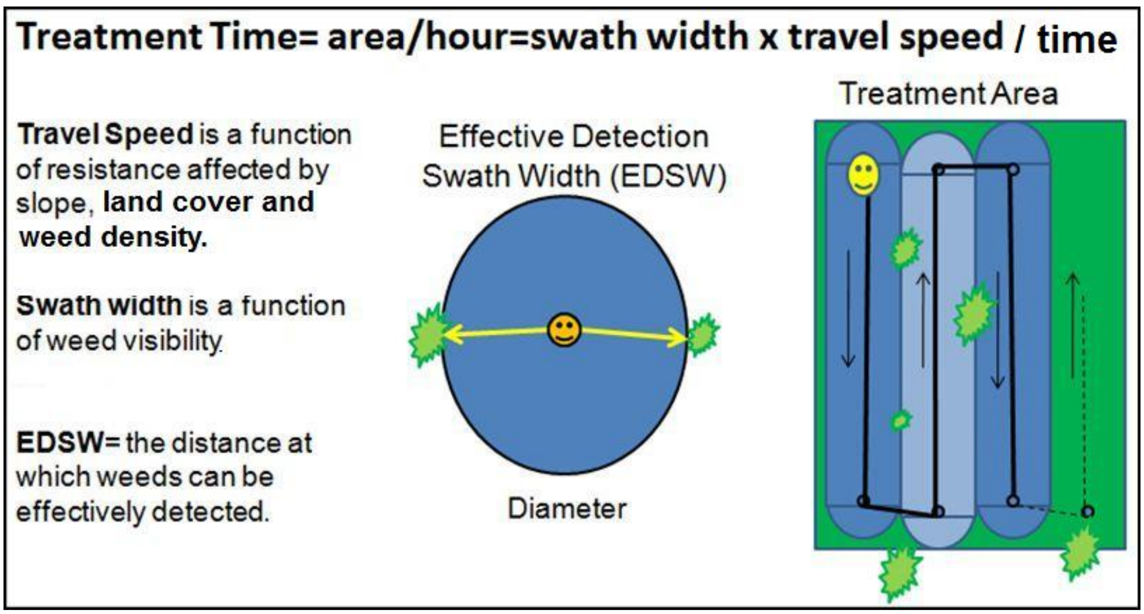

Figure 3-6. Visibility affects swath width. Visibility determines effective detection swath width (EDSW). Visibility is a function of weed development and land cover (adapted from Andersen 2007). Treatment time (area/hour) is determined by EDSW times travel speed.

Weed Visibility and Weed Species. The ability of the applicator to find a weed is influenced by the weed's visibility. Visibility of the weed is dependent the weed species. For example, a single Scotch thistle (*Onopordum acanthium*) plant can be large, growing to be 6 feet (2 meters) or taller. Its flowers are large and highly visible and can be seen for several hundred feet. In contrast, a Medusahead rye (*Taeniatherium caput-medusae*) plant is much smaller (less than 6 inches (15 cm) tall) with non-descript flowers. In grass, its visibility may be 10 feet (3 meters) or less.

Weed Visibility and Weed Development

Progressive weed development increases the weed's size which makes it more visible. Larger weeds are easier to see and identify (Goodwin et al. 2010). As the weed develops it will flower. Flowering may make the weed more visible by both increasing in height and by producing a flower with a high contrasting color. For example: a musk thistle rosette can be very small early in the spring and in short grass may have a visibility distance of 10 feet (3 meters). Later, when the same thistle is tall and flowering, it may be visible from several hundred feet (Figure 3-7).

Figure 3-7. Weed visibility dependent on weed development. Low visibility musk thistle (*Carduus nutans*) rosette in spring (left) and high visibility musk thistle flowering in late summer.

Weed Visibility and Land Cover. Weed visibility is also a function of land cover. The smaller and less dense the land cover the more visible the weeds. For example: In an area with low canopy cover land cover, garlic mustard plant rosettes can be highly visible (Figure 3-8). In an area with high canopy cover brush cover, garlic mustard plant rosettes may have low visibility (Figure 3-8, right).

Weed Visibility and Weed Canopy Cover. As weed canopy cover or infestation size increase, weed visibility increases. For example, a single garlic mustard rosette is small and not very visible. Garlic mustard infestations when established grow in very dense stands. These carpeted areas can be very visible (Figure 3-8, left).

Figure 3-8. Weed visibility dependent on weed canopy cover and land cover**.** High visibility garlic mustard in an area with low canopy cover land cover is shown (left); and low visibility garlic mustard in high canopy cover land cover is shown (right). As weed canopy cover increases weed visibility increases. A large patch (left) is more visible than a single plant.

Weed Visibility Models and Measures. Weed development models have also been created that can determine at what dates weed will develop to different stages (rosette, bolting, flowering, green seed and mature seed, (Lowry et al. 2007). These models can provide weed visibility information for invasive weed treatment areas. With a treatment time model, land managers could utilize visibility information to time treatment so weeds are treated at optimal development and visibility. They may also be able to create accurate treatment time estimates.

Treatment Time Model Benefits. With a full treatment time model, land managers could utilize weed canopy cover, slope, land cover, and weed visibility information to create accurate treatment time estimates. The model could: 1) establish a treatment time and cost standard; 2) assist contractors and land managers more precisely plan and manage limited resources; and 3) justify costs to funding sources. The purpose of this chapter was to explore the relationship of the primary hypothesized variables (slope, weed canopy cover, land cover, and weed visibility) and other variables that affect treatment time to develop a treatment time prediction model.

Materials and Methods

A partnership was established with the Department of Plants, Soils, and Climate at Utah State University, Providia Management Group (PMG Environmental LLC) and Jardyne Technologies to evaluate herbicide treatment data in 2013. From May to October 2013, PMG's backpack crews treated weeds in Northern Utah and Southwestern Idaho at six different locations including: a mountainous ski area, a mountainous watershed canyon, a high elevation meadow, a riparian valley, a steep hilly grass-restored pipeline right-of-way, and a high elevation mountainous city and surrounding area.

The SSW was used for data capture with an associated backpack spray tank, hand pump, and adjustable spray nozzle.

It was hypothesized that four primary variables influence treatment time: slope, weed canopy cover, land cover, and weed visibility. Other variables were also evaluated. The variables were statistically evaluated to determine their relationship to treatment time and to develop a treatment time model (Figure 3-9).

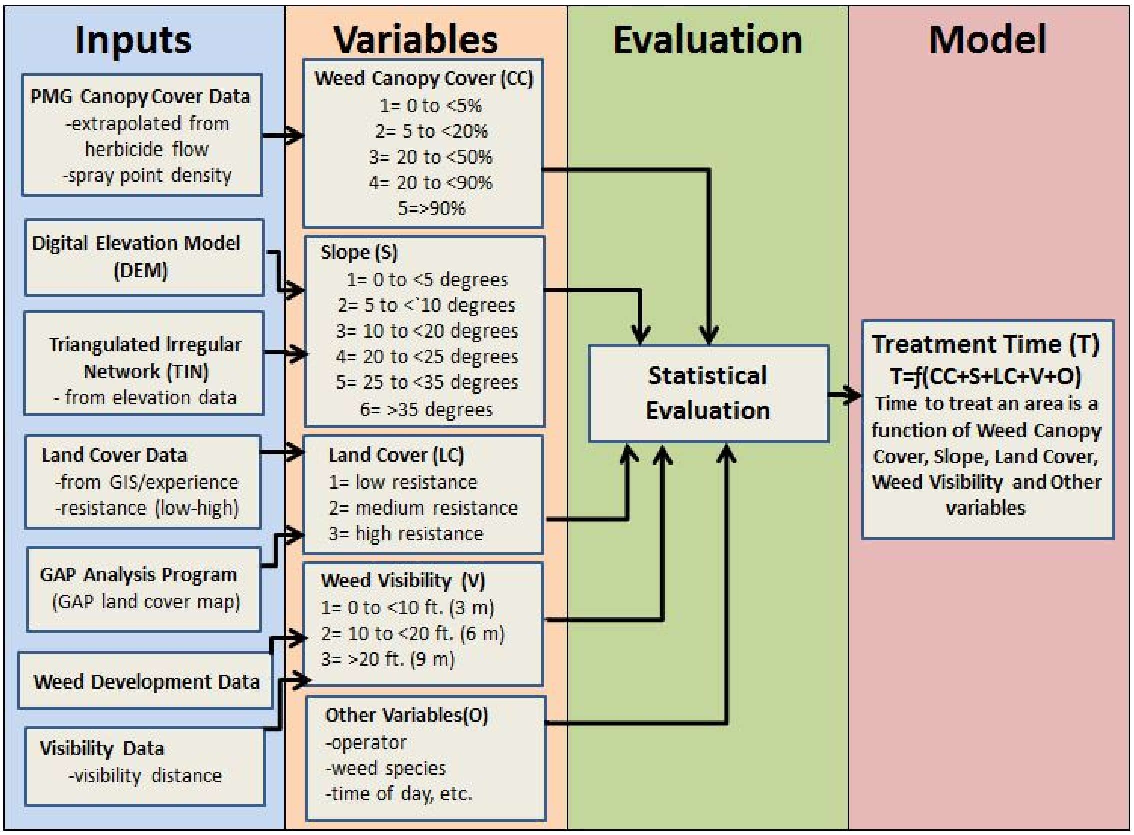

Figure 3-9. Model development flow and sources of data**.** Invasive weed treatment time (T) was hypothesized to be primarily dependent upon weed canopy cover (CC), slope (S), land cover (LC), and weed visibility (V). The model flow derived variables from a variety of inputs. The variables that contribute to treatment time were statistically evaluated to develop a model.

Data Development and Mapping. The test areas were mapped and evaluated using ArcGis® (ESRI, Redlands, CA, USA) and Manifold® (Professional Edition, Wanchai, Hong Kong) mapping programs. Areas were separated with grids and evaluated in association with the United States Geological Survey (USGS)10 meter Digital Elevation

Models (DEMs) (“10, 30, & 90 Meter Elevation Models (USGS DEMs) | Utah Mapping Portal,” 2014). Treatment time was the GPS recorded time that an operator was within each 10 meter area. A full description of data development is found in Appendix B.

Slope. Slope was obtained from the 10 meter DEM and recorded in degrees. Areas were gridded and evaluated in association with the 10 meter DEM, (Figure 3-10).

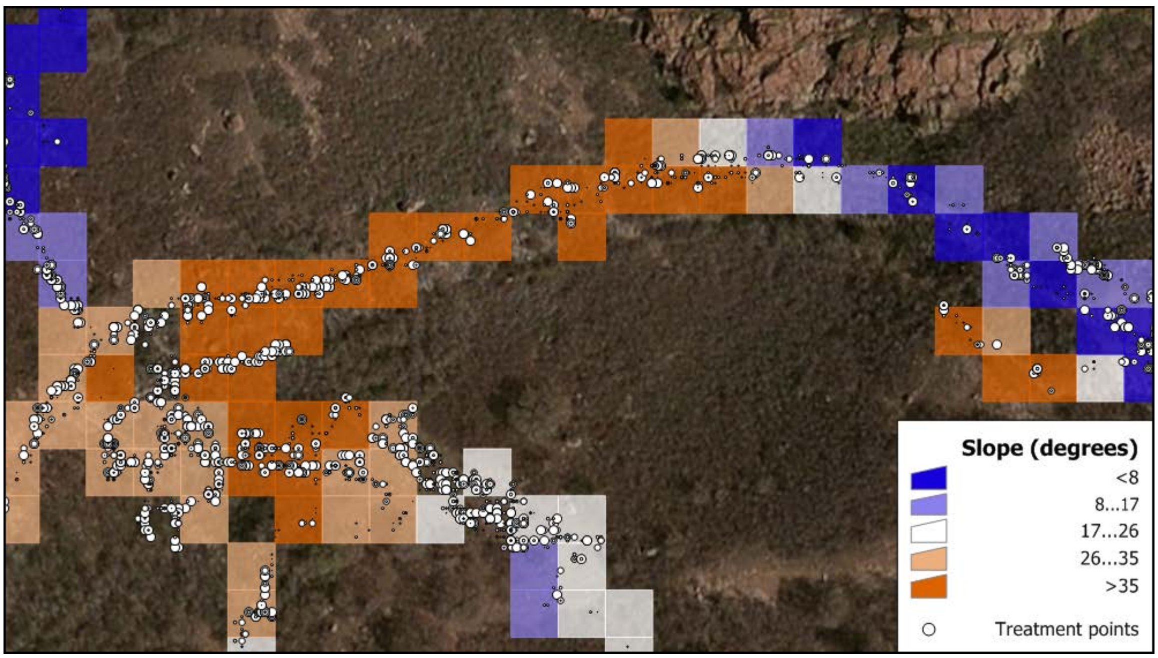

Figure 3-10. Slope and grid from digital elevation model (DEM**).** These were 10 m DEM’s from the U.S. Geological Survey. Treatment time was the GPS recorded time that the operator was within each of the 10 meter areas.

Vertical and Non-Vertical Movement on Slope. To account for the possible variation of vertical travel on areas of the same slope, the sum of absolute value of up and down elevation movement was recorded. It was hypothesized that the equivalent of four times the vertical rise in an area would be considered efficient. More than four times would be inefficient. Efficient movement would be the equivalent of travel up and down the area two times. The up and down movement on slope was categorized (0= no slope or efficient movement, 1=inefficient movement).

Weed Canopy Cover and Density. Weed canopy cover per area was obtained by summing the "Smart" spray gun recorded flow per grid area and dividing it by the backpack calibrated flow per acre (24 gal/acre, 91 liters/acre). Weed density was calculated by summing the treatment points per grid area (Figure).

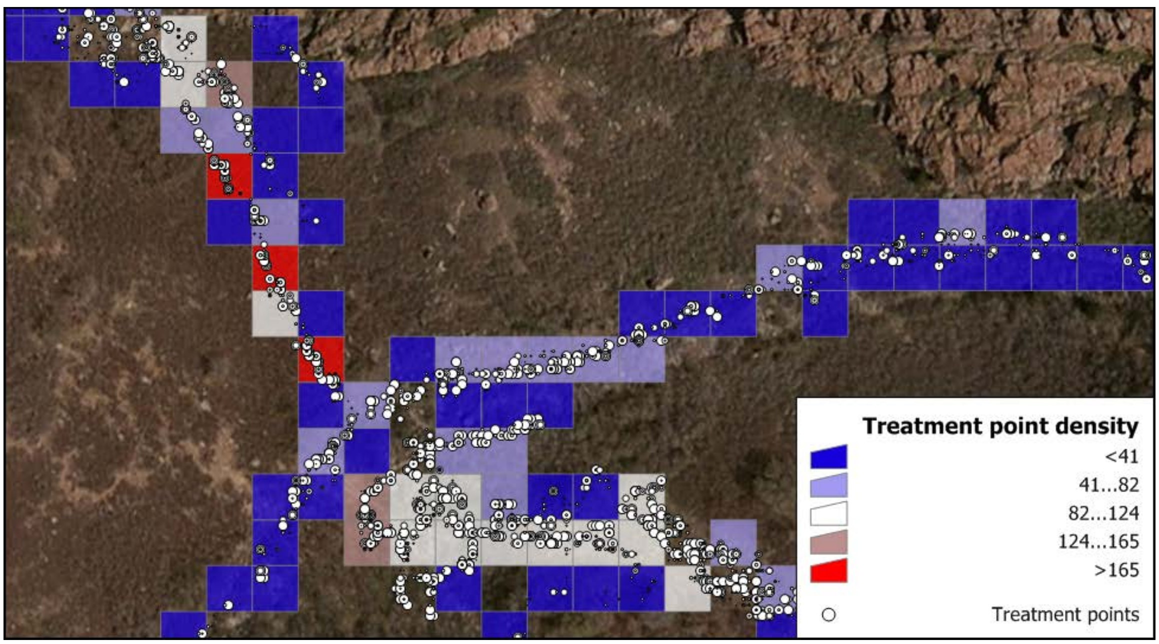

Figure 3-11. Treatment point density of grid areas. Canopy cover measures were derived from herbicide flow per area and treatment points per area.

Land Cover. Land Cover categories were based on Soule and Goodman's (1972) categories, with refinement by Jobe and White (2009). The categories were low, medium, and high resistance compared to paved ground (energetic coefficient (EC) = 1.0) as follows (Table 3-1):

Low resistance areas (cat.1, EC=1.2) were defined as predominantly soil or herbaceous cover from 0 to 0.5 meters high. These land cover areas had low resistance to the applicator's movement and were areas where the applicator could maintain a normal gait.

Medium resistance land cover areas (cat.2, EC=1.31) were defined as predominantly shrub cover 0.5 to 1.0 meters high. This land cover provided moderate resistance to the applicator's movement. In these areas the applicator had to step over, push through or go around shrubs.

High resistance (cat.3, EC=1.58) land cover areas were defined as predominantly shrub cover greater than 1 meter high. This land cover provided high resistance to the applicator's movement. In these areas the applicator had to push through limbs, climb over low horizontal branches, duck or crawl under branches, or look for alternate routes into treatment areas. Likewise Jobe and White (2009) described the *Rhododendron* and *Kalmia* species areas (cat. 3, high resistance) where they did their study as "thickly tangled, evergreen stands, sometimes referred to as 'hells'…are extremely difficult to travel through, and represent a significant barrier."

Table 3-1. Land cover categories and energetic cost coefficients. Energetic cost coefficients are a measure of resistance for herbicide applicator travel on different land covers.

Land Cover Categories and Energetic Cost Coefficients			
Resistance	PMG categories (hypothesized)	Soule & Goodman (1972)	Cost Coefficient
None	Paved Road	Paved Road	1.00
1-Low	Herb Height 0 to 0.5 meters	Dirt	1.20
2-Medium	Shrub Height 0.5 to 1.0 meters	Light Brush	1.31
3-High	Shrub Height > 1.0 meters	Heavy Brush	1.58

Land cover maps were obtained using the USGS national Gap Analysis Program (GAP) land cover map (USGS, 2013) (Figure 3-12 , left), and a GIS drawn map (GISd, Figure 3-13, left) created with GIS satellite imagery by staff who had treatment experience in the areas. A third map (Gred) was reduced from the GAP map to three resistance categories and overlayed to the 10 meter treatment areas (Figure 3-12, right).

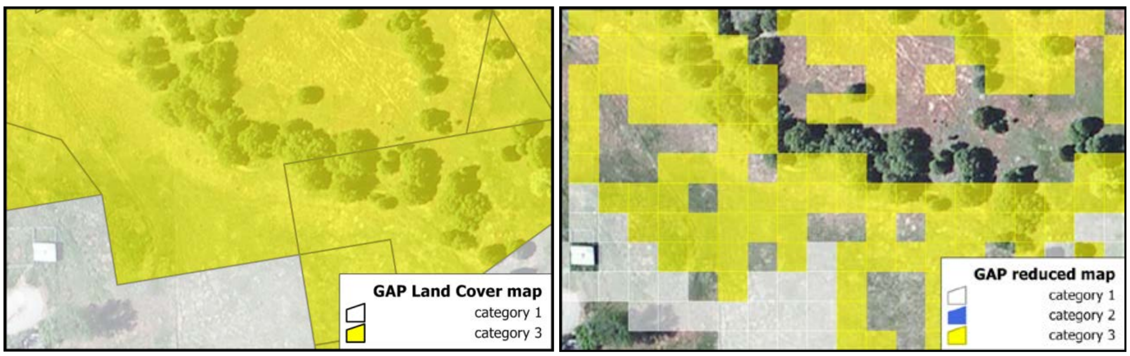

Figure 3-12. GAP and GAP reduced land cover maps. GAP land cover map (GAP, left)), and the GAP map reduced to 3 resistance categories (Gred, right). The squares are DEM 10 m^2 areas where treatment occurred. The white areas were delineated by GAP as agriculture (cat. 1=low resistance), and yellow areas are forest areas (cat. 3=high resistance).

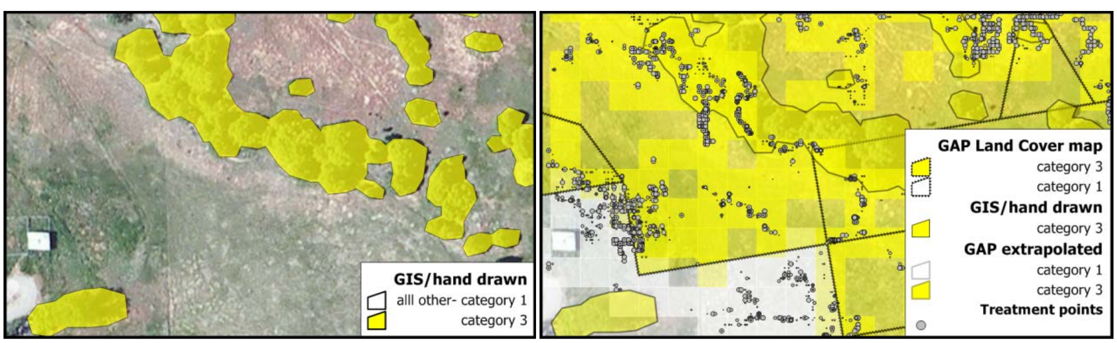

Figure 3-13. GISd and combined land cover maps. GIS hand drawn land cover map (GISd, left) showing high canopy cover areas (category 3) and all three maps overlapped (right).

The Gred map was adapted to resistance categories based on land cover as follows: grass areas (cat. 1), shrub areas (cat. 2) and woodlands (cat. 3). Examples of land cover in those categories are shown in Table 3-2.

Table 3-2. GAP Reduced (Gred) land cover category examples. The Gred LC map was adapted to 3 resistance categories based on land cover. The categories were: grass areas (cat. 1), shrub areas (cat. 2) and woodlands (cat. 3).

GAP Reduced (Gred) Landcover Category Examples		
LC Categories	Macro Code	Ecological Systems Name
1	M332	Introduced Upland Vegetation - Annual Grassland
2	M169	Great Basin Xeric Mixed Sagebrush Shrubland
2	M049	Rocky Mountain Lower Montane-Foothill Shrubland
3	M020	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland
3	M026	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland
3	M034	Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland
3	M022	Rocky Mountain Bigtooth Maple Ravine Woodland

Weed Visibility. A categorical description was developed for this project to report the effective detection distance (EDD), or the distance at which an individual weed of the primary treatment species could be identified. : 1. <10 feet (3 meters); 2. 10-20 feet (3-6 meters); 3. 21-40 feet (6-12 meters); and 4. >40 feet (12 meters) (Table). Weed applicators made a visual EDD measure estimate of the primary treatment species each treatment day and recorded the category. Those category measures were added to the area maps and data.

Table 3-3. Weed visibility categories. The categories to report the effective detection distance (EDD), and number of treatment areas of each category (n).

Weed Visibility Categories		
Category	Description	n
1	≤ 10 feet (3 meters)	153
2	11-20 feet (3-6 meters)	2509
3	21-40 feet (6-12 meters)	2448
4	>40 feet (12 meters)	2578

Multi-Variable Model Evaluation. Evaluations were made using the statistical package R (R Development Core Team 2014) with the general linear model (lm) and the “lsmeans” (Length 2014) package. It was graphed using the “ggplot2” package (Whickham 2009) and Microsoft Excel (Microsoft 2007). The full model was:

Model 1

$$\mathbf{T_{Tot} \sim \mathit{f}(CC+LC+S+V+UD+O)}$$

Total Estimated Treatment Time (T_{Tot}) is defined as the time it takes to treat weeds in an area. It is primarily a function of Canopy cover (CC)+Land Cover(LC)+Slope(S)+Weed Visibility(V)+Up & Down Travel (UD) and other variables (O).

Another model was examined that separated Total Estimated Treatment Time into components Treatment Time and Rest Time as follows:

Model 2

$$\mathbf{T_{Tot} = Treatment\ Time\ (T_t) + Rest\ Time\ (R_t)}$$

Total Estimated Treatment Time (T_{Tot})=Treatment Time(T_t) + Rest Time(R_t). Where Treatment Time (T_t) is the time it takes the applicator to travel to, locate and spray weeds; and Rest Time (R_t) is defined as stationary, non-treatment time while the applicator recovers from fatigue. Both T_t and R_t were evaluated as functions of Canopy *cover(CC)+Land Cover(LC)+Slope(S)+Weed Visibility(V) Up & Down Travel (UD) + other variables (O) as follows:*

$$\textbf{Treatment Time } (\mathbf{T_t}) \sim f(\mathbf{CC+LC+S+V+UD+O})$$
$$\textbf{Rest Time } (\mathbf{R_t}) \sim f(\mathbf{CC+LC+S+V+UD+O})$$

Single-Variable Model Evaluation. To compare data from this project with other models, an attempt was made to isolate and evaluate the effect of each individual variable independent of the other influential variables. To do this, data that emphasized other variables was removed.

Results

Model 1: Canopy Cover as a Function of Total Treatment Time. Both linear and categorical responses were evaluated. Canopy cover based on flow as a function of total treatment time (T_{Tot}) was statistically significant and had a large influence on the model (R^2 =0.584). Log transformation did not improve the fit. Categories were evaluated and established as follows (cat.1=0 to <0.05, cat.2=0.05 to <0.2, cat.3=0.2 to <0.5, cat.4=0.5 to <0.9=4, cat.5= >or =.9). These categories are close to the Daubenmire classification (Table 3-4), one of several canopy cover class systems (Forest Service n.d.; North American Weed Management Association 2002).

Table 3-4. PMG and Daubenmire's (North American Weed Management Association 2002) canopy cover categories.

Canopy Cover Categories	
Daubenmire	PMG
0 - 1.0%	0 - <5.0%
1.1 - 5.0%	
5.1 - 25%	5.0 - <20%
25.1 - 50%	20 - <50%
50.1 - 75%	50 - <90%
75.1 - 95%	
95.1 - 100%	>90%

The category fit (p=<2.2e-16, R^2 =0.5607) was close to the linear model fit. Canopy cover based on spray points as a function of total treatment time (T_{Tot}) had a much better fit (p=<2.2e-16, R^2 =0.6964).

Model 2: Canopy cover (CC) as a function of treatment time (T_t). In Model 2, Canopy cover based on flow as a function of treatment time (T_t) was statistically significant (p=<2.2e-16, R^2=0.6674). The category fit (p=<2.2e-16, R^2 =0.633) was close to the linear model fit. Canopy cover based on spray points as a function of treatment time (T_t) had a better fit (R^2=0.7809).

Model 2: Canopy cover (CC) as a function of Rest (R_t). Canopy cover based on flow as a function of rest time (R_t) was statistically significant (p=<2.2e-16, R^2 =0.1008). Canopy cover based on spray points as a function of rest time (R_t) had a slightly smaller fit (R^2 =0.09484).

Model 1: Slope as a function of Total Treatment Time (T_{Tot}). Slope as a function of total treatment time (T_{Tot}) did not have a linear response, so categories were evaluated and established (cat.1 =0 to <5°, cat.2 =5 to <10°, cat.3 =10 to <20°, cat.4=20 to <25°, cat.5=25 to <35°, cat.6=>35°). Slope was statistically significant (p=0.00672), R^2 =0.00144).

Model 1: Up & Down Category Statistical Evaluation. Up & down category as a function of total treatment time (T_{Tot}) was statistically significant (p=0.00054, R^2=0.043).

Model 2: Slope Statistical Evaluation. In model 2, the slope categories as a function of treatment time (T_t) were statistically significant (p=0.00518, R^2 =0.00152). Slope as a function of rest time (R_t) could be summarized in less categories (cat.1=0 to <20°, cat.2=20 to >35°). It was statistically significant (p=0.00054, R^2=0.223).

Model 2: Up and Down Category Statistical Evaluation. Up & down category as a function of rest time (R_t) was not statistically significant (p=0.624). Up & down category as a function of treatment T_t) was statistically significant (p=2e^{-16}, R^2 =0.112).

Model 1: Land Cover as a function of Total Treatment Time (T_{Tot}). Land cover based on the GISd map as a function of total treatment time (T_{Tot}) was statistically significant (p=<2.2e-16, R^2=0.03155). Transformation did not improve the fit. Land cover based on the GAP map as a function of T_{Tot} was statistically significant (p=<2.2e-16, R^2 =0.02247). A log transformation improved the fit slightly (R^2 =0.02514). Land cover based on the 3 categories derived from the Gred was statistically significant, but had a small influence on the model (p=<2.2e-16, R^2=0.009287). A log transformation improved the fit slightly (R^2 =0.01127).

Model 2: Land Cover (LC) as a function of treatment time (T_t). Land cover based on the GIS map as a function of T_t in Model 2 was statistically significant (p=<2.2e-16, R^2 =0.03164). Transformation did not improve the fit. Land cover based on the GAP map as a function of T_t in Model 2 was statistically significant, but had a small influence on the model ($p=<2.2e-16$, $R^2=0.02603$). A log transformation improved the fit slightly ($R^2=0.02675$). Land cover based on the GISd LC as a function of T_t *in* Model 2 was statistically significant ($R^2=0.01343$). A log transformation improved the fit slightly ($R^2=0.01432$).

Model 2: Land Cover (LC) as a Function of Rest (R_t). Land cover based on the GISd map as a function of R_t in Model 2 was statistically significant ($p=<2.2e-16$, $R^2=0.01093$). Transformation did not improve the fit. Land cover based on the GAP map as a function of R_t in Model 2 was statistically significant ($p=<2.2e-16$, $R^2=0.01409$). A log transformation improved the fit slightly ($R^2=0.0177$). Land cover based on the Gred map as a function of R_t was statistically significant ($p=5.944e-10$, $R^2=0.002732$). A log transformation improved the fit ($p=1e-05$, $R^2=0.005254$).

Model 1: Weed Visibility as a function of Total Treatment Time (T_{Tot}). Weed visibility as a function of total treatment time (T_{Tot}) was statistically significant ($p=6.386e-12$, $R^2=0.006763$). A log transformation did not improve the fit.

Model 2: Weed Visibility (V) as a function of treatment time (T_t). Weed visibility as a function of T_t in Model 2 was statistically significant ($p=6.801e-11$, $R^2=0.00614$). Transformation did not improve the fit.

Model 2: Weed Visibility (V) as a Function of Rest (R_t). Weed visibility as a function of R_t in Model 2 was statistically significant ($p=1.199e-5$, $R^2=0.002927$). Transformation did not improve the fit. The second class (11-20 feet (3-6 meters)) was not significant.

CHAPTER 4

DISCUSSION AND CONCLUSION

The Hypothesized Variables: T~***f***(D+LC+S+V+UD)

Following is a description of the hypothesized variables effect on treatment time. A summary of their effects based on R^2 is shown in Table 4-1.

Table 4-1. The hypothesized variables and their effect on treatment time. The effect on treatment time in Model 1 & 2 based on R^2. Canopy cover is the most influential factor.

Treatment Time vs. Variables (R^2)			
	Models		
Variables	T_{tot}	T_t	R_t
Canopy Cover (CC)	0.5369	0.6197	0.0591
Land Cover (LC)	0.0289	0.0289	0.0102
Slope (S)	0.0015	0.0015	0.0050
Visibility (S)	0.0076	0.0069	0.0032
Up Down Travel (UD)	0.0580	0.0745	0.0014
Total R^2	0.5694	0.6496	0.0770

Weed Canopy cover (D). Canopy cover was the most influential factor affecting treatment time based on R^2 (0.5369, Table 4-1). As weed canopy cover increases, treatment time increases (Figure 4-1).

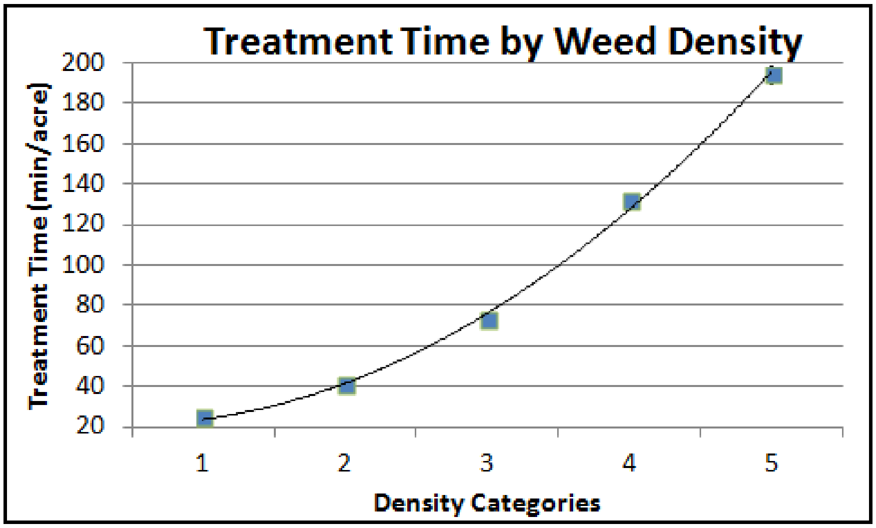

Figure 4-1. Treatment time affected by weed canopy cover. As weed canopy cover increases, treatment time increases

Canopy cover based on spray points had a better model fit than canopy cover based on flow (Table 4-2). When Rest is removed in Model 1, spray points explains almost 80% of the variability in this model (R^2=0.7809). It may seem counter intuitive that spray points have a better fit than spray flow because spray points could represent a wide range of treatment: from a fraction of a second with partial flow to a full second of open flow.

Table 4-2. Canopy cover effect on treatment time. Canopy cover as measured by spray points had a better fit than canopy cover based on flow.

Treatment Time vs. Canopy Cover Measures (R^2)			
		Models	
Measures	T_{Tot}	T_t	R_t
Flow Categories	0.5369	0.6197	0.0591
Spray Flow	0.5696	0.6560	0.0618
Spray Points	0.6844	0.7725	0.0886

Much of the standard weed canopy cover monitoring is done in canopy cover (Forest Service n.d.; North American Weed Management Association 2002). The measured treatment flow was the amount of liquid it took to cover the weed canopy per area treated. The calibrated flow was the herbicide mix it would take to cover the whole area. Treatment flow and calibrated flow would seem to be closely related and could be recommended to be used to calculate canopy cover as follows.

Canopy cover = treatment flow per area/calibrated flow per area

Canopy Cover-Only Model Equation. With canopy cover, independent of the other variables, the linear model had a better fit than the categorical model and would be easier for use. This may not be the case when working with multiple variables. As weed density increased, both treatment time and rest increased. The response model as density increases in hours per acre is $y=2.7x+0.36$ (Figure 4-2). This most simple model may be useful for managers and contractors in calculating treatment costs and preparing bids. If proven accurate over time in areas that are not highly influenced by other variables, it may be useful in establishing a standard for use.

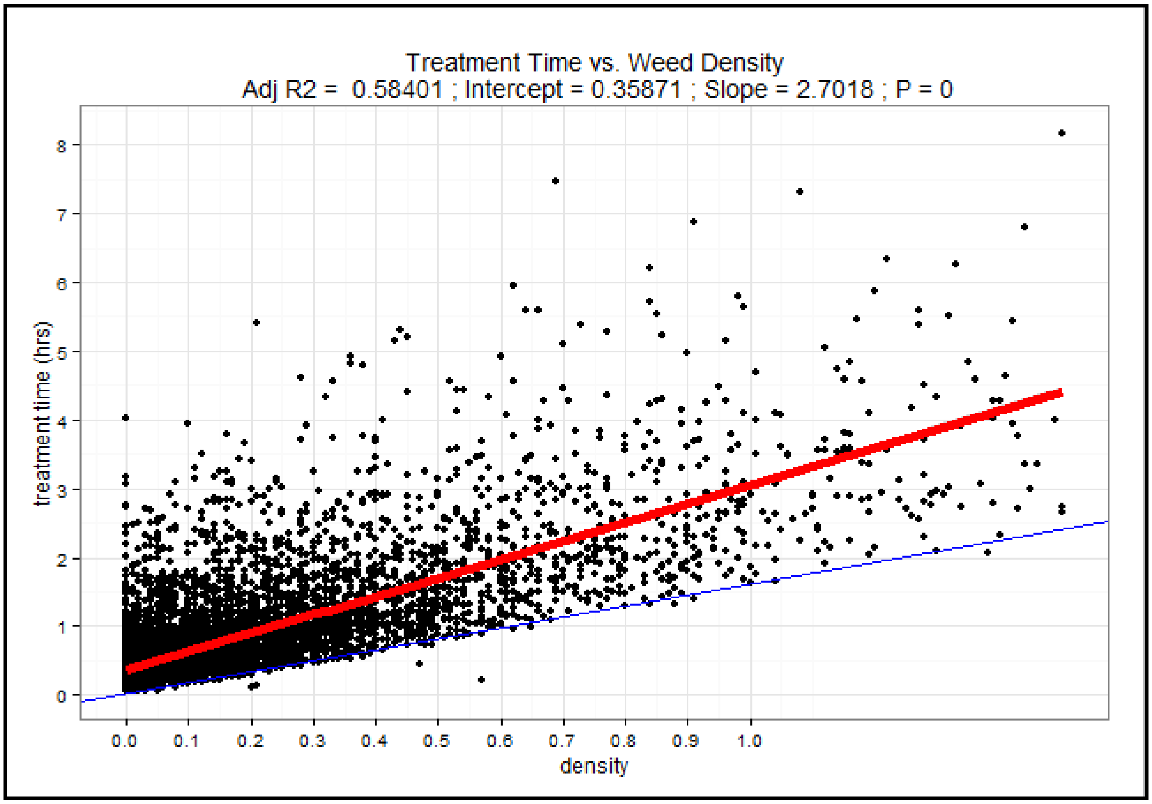

Figure 4-2. Treatment time vs. canopy cover model (density). As canopy cover increased, both treatment time and rest increased. The response model (red line) as canopy cover increases in hours per acre area is y=2.7x+0.36. The blue line is an estimate that suggests a limit to how fast an area can be treated based on the density. The model equation is y=1.6x + 0.02. Herbicide canopy cover for calibration exceeded 100% in many of the areas.

Below the Line. The blue (Figure 4-2) is an estimate that suggests a limit to how fast an area can be treated based on the weed canopy cover. This may be the most useful information to contractors when calculating break even costs and for managers when evaluating reasonable treatment bids. The manager who accepts a bid below cost may expect poor or incomplete weed treatment. The model equation for this bottom line is y=1.6x + 0.02. Examples of calculations of treatment time averages and minimums based on the models are given in Table 4-3.

Table 4-3. Treatment time vs. weed canopy cover. Model and calculation examples.

Treatment Time Calculations per Acre Due to Weed Canopy Cover		
Canopy Cover (x)	Treatment Time (avg hrs) $y=2.7(x)+0.36$	Treatment Time (min hrs) $y=1.6(x)+0.02$
1%	0.39	0.04
5%	0.50	0.10
25%	1.04	0.42
50%	1.71	0.82
75%	2.39	1.22
95%	2.93	1.54

Slope (S). The slope effect on treatment time was significant but has a small effect on total treatment time based on R^2. There is no clear pattern of increase or decrease based on means and standard errors (Figure 4-3).

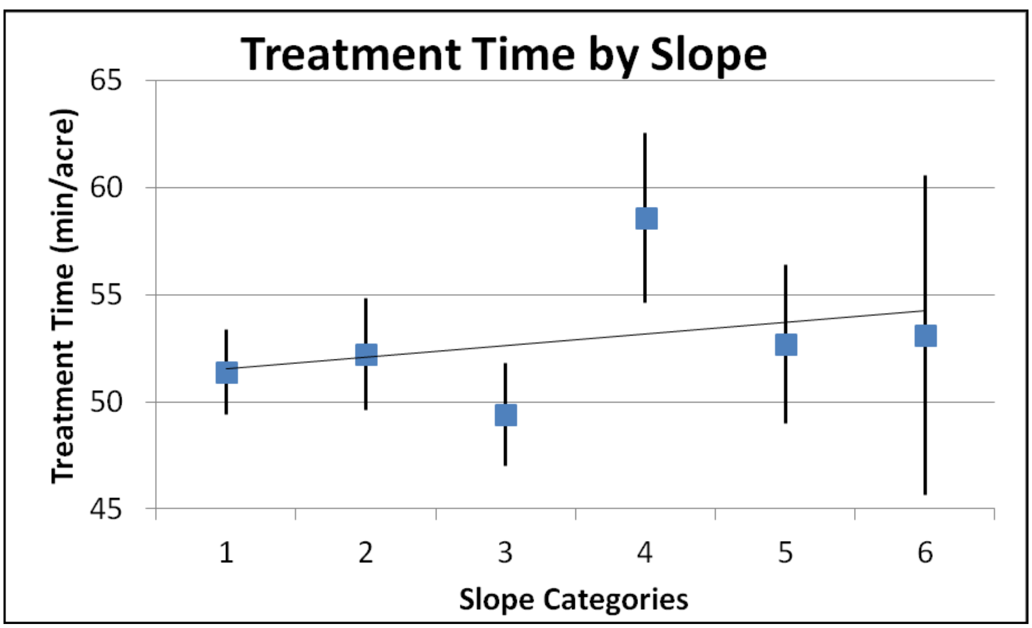

Figure 4-3. Treatment time affected by slope (means and standard errors). A poor correlation.

Slope-Only Model Evaluation. A slope vs. speed model was developed based on the average GPS speed in areas of different slopes. The areas with treatment point sums greater than 5 and land cover categories greater than 1 were removed to eliminate the effect of those variables. Only the highest 20% of GPS speed areas in each slope category were used to develop a slope-only model. The highest 20% were taken to so that areas where the applicator was stopped would not affect the model. A second order polynomial fit line was calculated using Excel (R^2 = 0.5804, Figure 4-4).

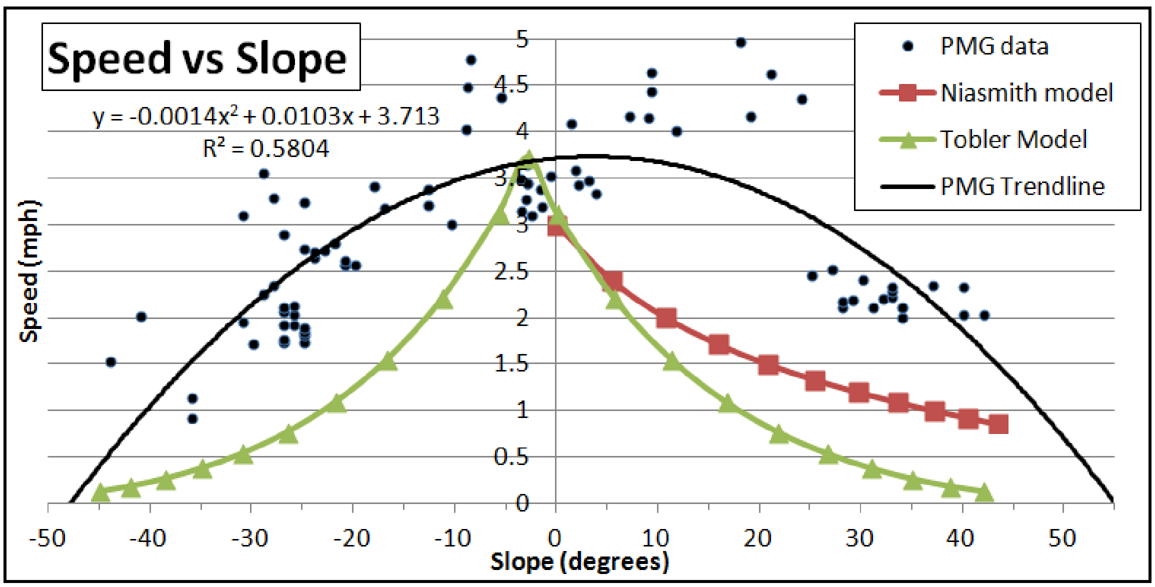

Figure 4-4. Walking speed vs. slope models. The PMG points represent the slope and average speed on a 10 meter DEM grid area. Points represent the top 20% of GPS speeds in treatment areas with low treatment points (<5). The PMG data line fit is R^2 = 0.5804. The curve is different than the other models (parabola vs. inverse log curve).

Discussion and Model Suggestions

Model 1: Effect of Up and Down Movement Efficiency. In Model 1, the slope effect on treatment time was significant but has a small effect on total treatment time. The up and down movement efficiency on a slope of greater than or equal to 20° impacts the treatment time to a small extent. This may be due to the increased applicator fatigue and rest with increased travel up and down a slope. Efficient movement on a slope decreases treatment time compared to inefficient movement even when the travel distance and swath widths are assumed the same (Figure 4-5). Inefficient swathing, however, increases the distance traveled based on increasing surface distance with increasing slope. Efficient treatment movement can be taught to applicators or integrated into treatment planning when working high sloped areas. This can decrease treatment time and conserve applicator energy.

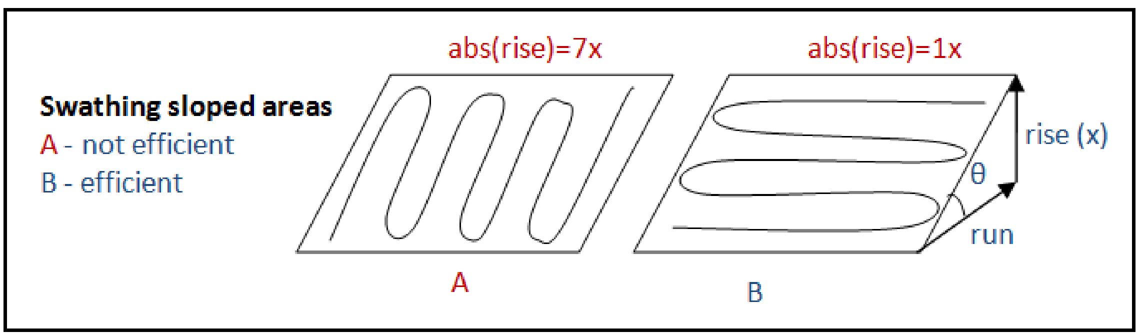

Figure 4-5. Up and down movement efficiency on a slope. The up and down movement [abs(rise)] efficiency on a slope is important to the treatment time. Applicator fatigue and rest time can increase with increased travel up and down a slope. Inefficient swath patterns can greatly increase the up and down travel (7x in this illustration-A vs. B). Distance traveled also increases with inefficient swathing based on increasing surface distance with increasing slope.

Model 2: Treatment Time~Slope, (T_t~f(S)). In this model also, the slope is significant but has a small effect on applicator travel speed and resulting treatment time. The applicators travel speed may be more highly dependent on other variables than by slope.

Model 2: Treatment Time ~Up and Down Movement Efficiency ($T_t \sim f(UD)$). The up and down movement efficiency on the slope was important to the treatment time. Inefficient movement on a slope physically slows the operator, thereby increasing treatment time. The applicator is slowed both traveling upwards and downwards as Langmuir suggested when traveling downhill on more difficult slopes (>12°) (Langmuir 1984).

Model 2: Rest ~Slope, ($R_t \sim f(S)$). In Model 2 the slope was significant and important to rest. At high slopes (20° and higher) the applicator fatigue and recovery time increases. This effect is not as clearly observed in Model 1. This may be due to the low proportion of rest time versus total treatment time. Average rest time in this project was only 10.1% of the total treatment time. This does suggest that the slope's primary influence in treatment time is through increasing rest time and not in decreasing applicator travel speed. Langmuir (1984) and others report that a hiker is slowed both traveling upwards and when traveling downhill on more difficult slopes (>12°). If evaluated, these slope based models may also be more affected by rest time than slowed movement from increasing slopes. Backpack herbicide treatment may have variables that are more limiting than travel speed. For example, during weed treatment at high weed densities, an applicator often travels at <1 mph. That speed according to the PMG Slope vs. Speed model (Figure 4-4) would compare with a +40° slope.

Model 2: Rest ~Up and Down Movement Efficiency ($R_t \sim f(UD)$). Up & down category as a function of rest time (R_t) was not statistically significant (p=0.624). This appears to validate the conservation of “work” that the up and the down travel cancel each other out in physical exertion.

Summary. Increasing slope increases rest time, which increases total treatment time. Increasing up and down movement efficiency increases the applicator travel speed, which decreases total treatment time.

Other slope model literature does not address rest or recovery time. In some exercise physiology literature recovery post exercise is mentioned, but recovery time is not added to movement time or accounted for (Gomeñuka et al. 2014). In the friction models it is not clear if rest is summed into the equation. In the hiking models, though not mentioned, rest is assumed to be averaged into total hiking time. These results may justify further evaluation of rest in the future.

Slope-Only Model Suggestions. Both rise distance and surface distance increase exponentially with increasing slope (Figure 4-6). This would cause an increasing proportion of resistance to applicator movement as slope increases. The increased rise per added degree at higher slopes would more quickly decrease travel speeds on those slopes. This would suggest that with a walking slope model, at higher slopes the curve would be steeper than at lower slopes. This agrees with the PMG Slope vs. Speed model curve (parabola), whereas the other models are just the opposite with steeper curve at lower slopes (Figure 4-4). An improved model could add additional accuracy to foot travel, friction and exercise slope models and their multiple uses. With the availability of GIS precision equipment, additional clarity could be added to the model in the future.

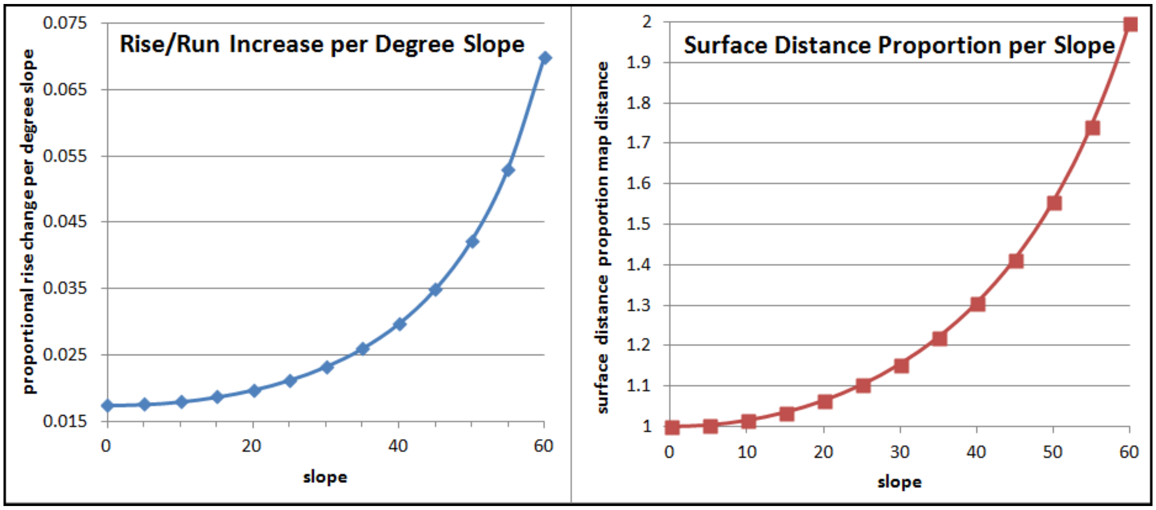

Figure 4-6 Vertical rise and surface distance increase exponentially with slope. Both rise distance (left) and surface distance (right) increase exponentially with increasing slope. This would cause an increasing proportion of resistance to applicator movement as slope increases, and gives evidence to a more parabola shaped model.

Land Cover (LC). As land cover resistance increases treatment time per area increases (Figure 4-7), though it tended to have a low correlation in this study (R^2= 0.0289). Land cover's correlation is higher than that of slope. This is surprising as Jobe and White (2009) found that increasing resistance due to both slope and vegetation increased energy costs, but slope to a much greater degree. They reported that doubling the resistance of slope increased energetic cost five-times more than doubling the resistance of vegetation.

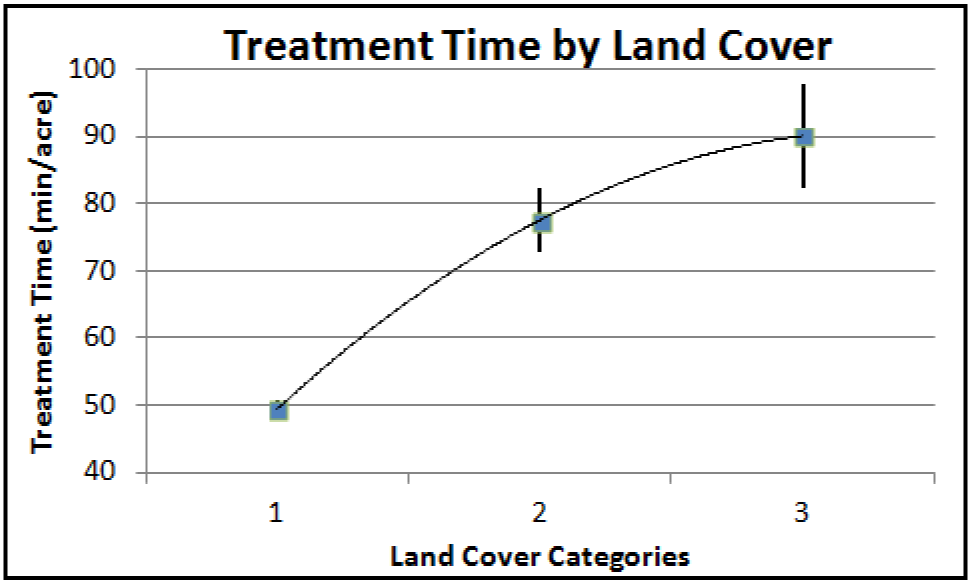

Figure 4-7. Treatment time vs. land cover (means and standard errors). As land cover resistance increases, treatment time per area increases.

Weed Visibility (V). As weed visibility increased treatment time decreased (Figure 4-8). On average, variation in increased visibility can decrease the treatment time by 21 minutes per acre (33%). However, this affect does not have as much impact as other variables in the model. For example, the effect of weed canopy cover can be close to 1000%, from 20 minutes per acre at low weed canopy cover to 200 minutes per acre at high canopy cover. The low visibility effect in this study may be due to: 1) treatment timing that maximized weed visibility and weed susceptibility to herbicides (Figure 4-9). “Smart” wand multi-season mapping that decreases search and treatment time by getting applicators to the location where weeds can be seen.

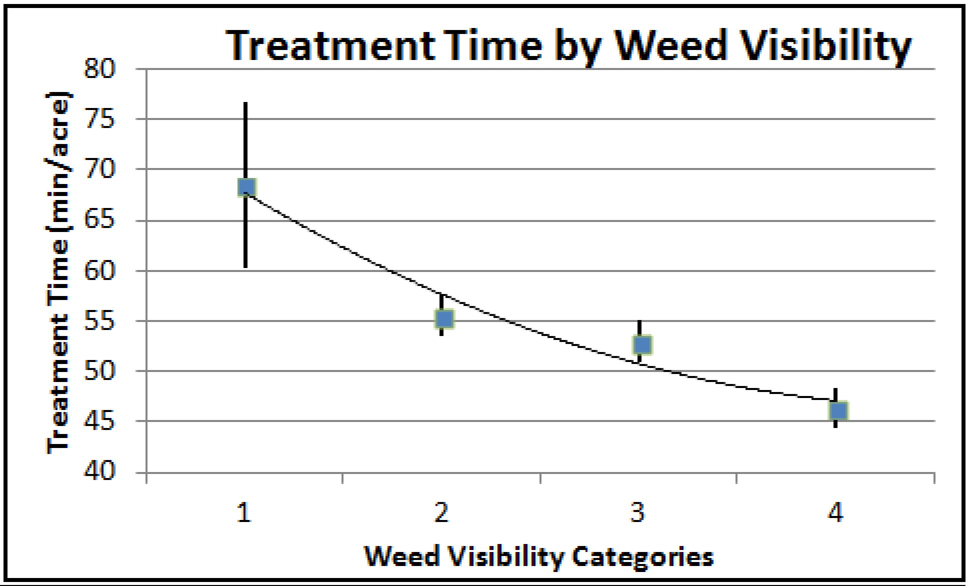

Figure 4-8. Treatment time vs. weed visibility (means and standard errors). As weed visibility increases, treatment time per area decreases.

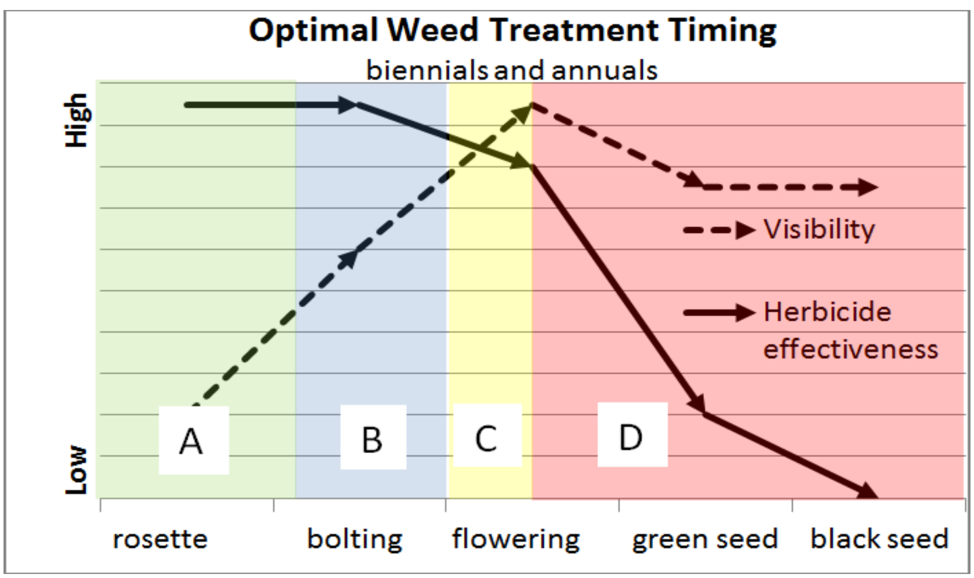

Figure 4-9. Optimal weed treatment timing on annuals and biennials. As weeds develop, weed visibility increases and herbicide effectiveness decreases. Optimal treatment time may be in area C (early flowering) when both visibility and herbicide effectiveness may be high.

Other Variables: T~$\boldsymbol{f}$(O)

Other variables and their effect on treatment time were evaluated (Table 4-4). These variables were of interest to understanding their effect on treatment time, but either had a small effect or would be difficult generally for use in a model. For example, the site or the treatment location was useful in understanding affects in this research, but may not be useful for land managers and contractors in general who would not be treating at those specific sites.

Table 4-4. Other (O) variables and their effect on treatment time. Affect based on R^2 values. Total is equal to other (O) variables added to hypothesized values (CC, LC, S, V, and UD)

Treatment Time vs. Other Significant Variables (R^2)			
		Models	
Variables (O)	T_{tot}	T_t	R_t
Month	0.0210	0.0248	0.0083
Weekday	0.0063	0.0053	0.0072
Hour	0.0107	0.0096	0.0083
Site	0.0305	0.0331	0.0170
Applicator	0.0092	0.0073	0.0170
Species	0.0211	0.0173	0.0220
Elevation	0.0089	0.0122	0.0068
Model Total	0.6130	0.6876	0.1174

Weekday and Hour. The weekday and hour effect on treatment time had a similar curve with an increase in treatment time after beginning, then a return to a lower treatment time (Figure 4-10 and Figure 4-11). The author's experience is that the applicator may overdo physically on Monday after returning to work from a weekend rest. The applicator then feels the effect on Tuesday and slows down. On Wednesday the applicator has adjusted to the new work week. There is a high variation in the beginning hour and the last hour (0600 and 1600, Figure 4-11, right). The fast treatment at the high variation periods may be due to walking through areas to get to treatment sites, or the swift return travel as applicators leave the treatment site at the end of the day. The high treatment time areas at these high variation periods may be due to coordination, or equipment adjustment or problems.

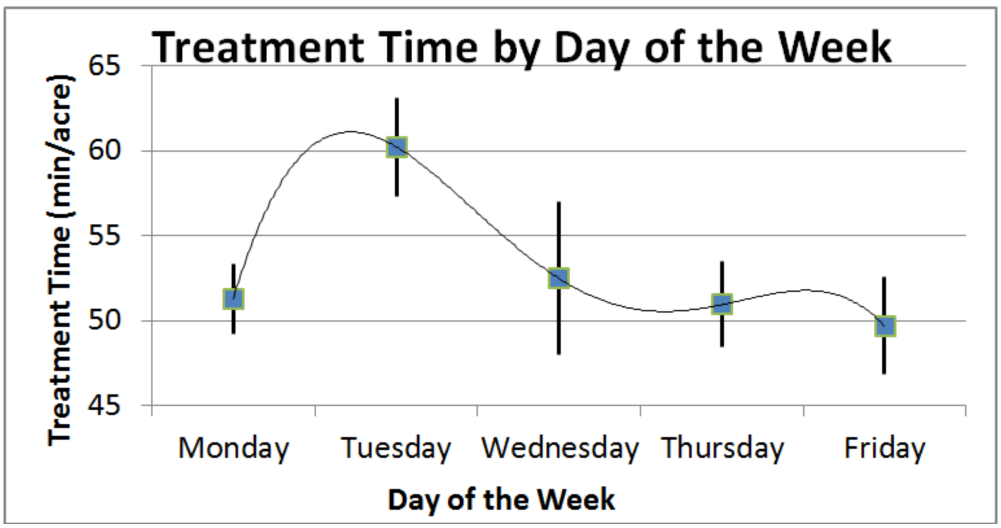

Figure 4-10. Treatment time vs. day (means and standard errors**).** There is an increase in treatment time on Tuesdays.

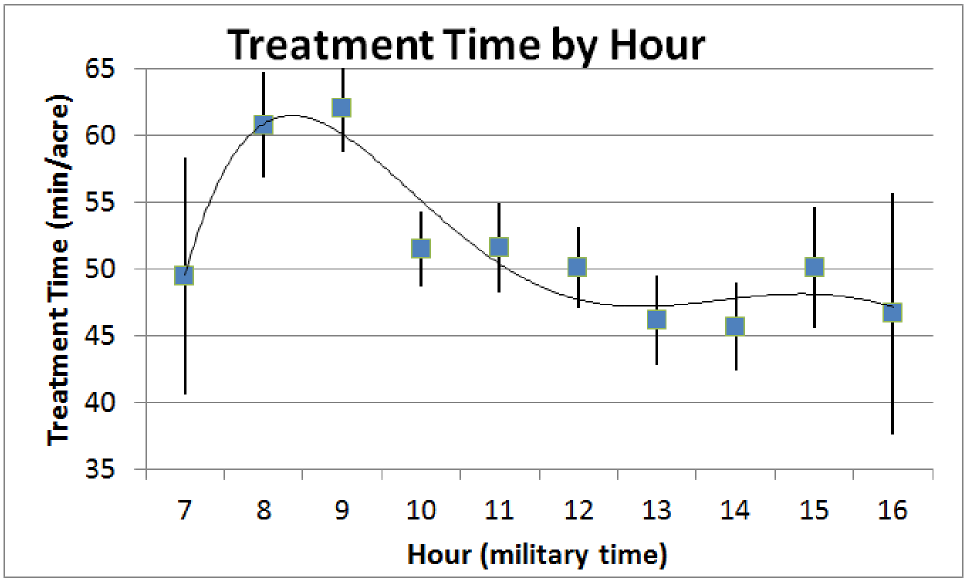

Figure 4-11. Treatment Time vs. time of day (means and standard errors**).** Hours are 0700-1600 (military time). There is a general decline of treatment time over the day, and a high variation at the beginning and end of the day.

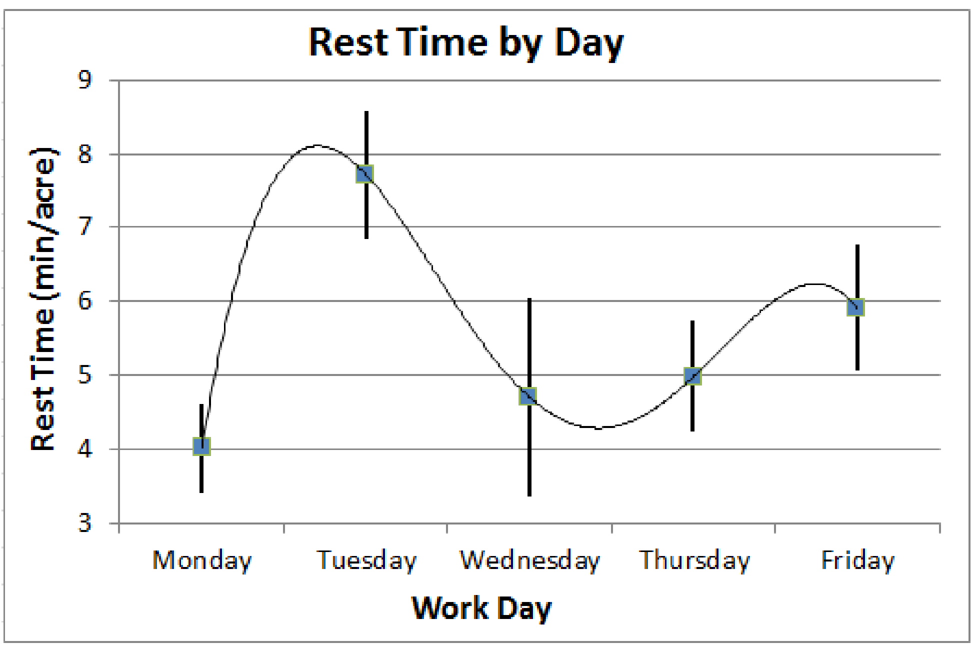

Figure 4-12. Rest Time vs. day (means and standard errors). There is an increase in rest time on Tuesdays.

Applicator Affected Treatment Time. Applicator treatment times are different as shown in Figure 4-13. These differences may be due to applicator motivation, training, physical fitness or other factors. For example, Applicator #1 had the lowest treatment time. This applicator was the crew lead, had the most experience at most of the locations, was responsible for the task getting done, and worked only half time treating in the field and half time in the office. The shorter treatment time of applicator #1 may be due to leadership motivation and to less fatigue due to less physical labor. In contrast, applicator 5 had a much higher treatment time than the other applicators. This applicator was transferred for 2 weeks from another crew and location. The applicator was new to the treatment areas and the crew. Continuity over time of an applicator or contractor on a specific project may increase treatment efficiency.

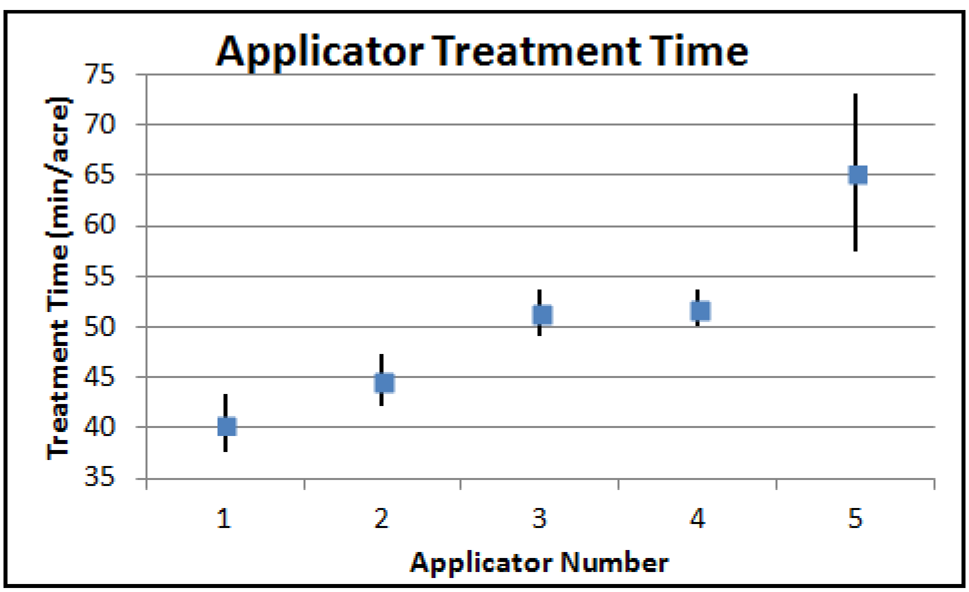

Figure 4-13. Treatment Time vs. applicator (means and standard errors). Applicator 5 was a transfer employee. Applicator 1 worked in the office half time.

Weed Species. Weed species affected treatment time (Figure 4-14). The high treatment time for myrtle spurge was likely due to its high weed canopy cover, location in high slopes, and dense land cover. It was treated in a steep mountainous area with cliffs and dense scrub oak. In contrast, the spotted knapweed had low canopy cover and was treated in a disturbed construction area where the weeds were highly visible.

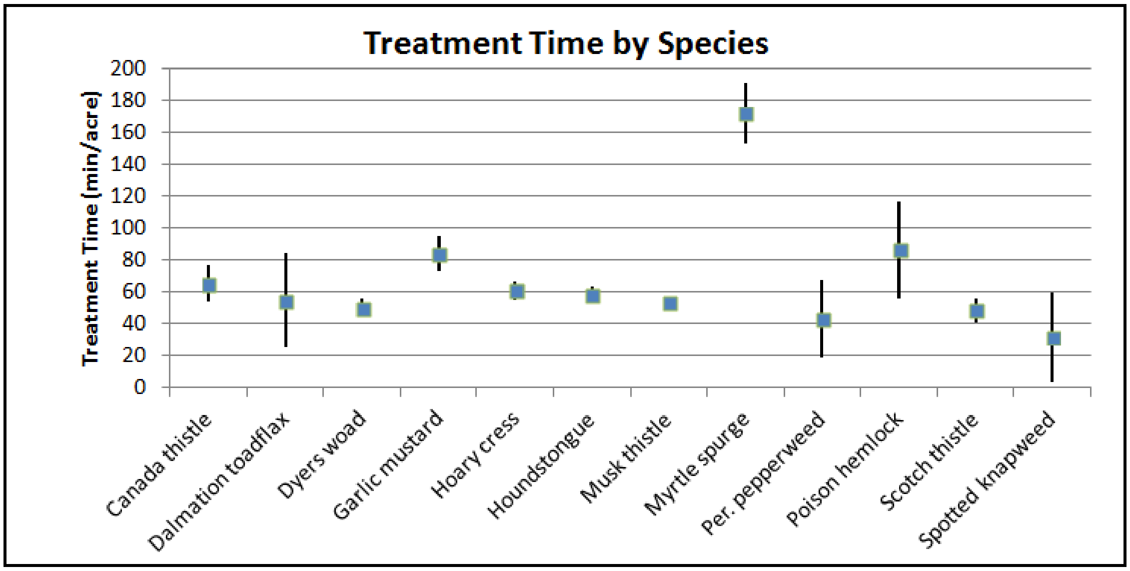

Figure 4-14. Treatment Time affected by weed species (means and standard errors).

Elevation. Elevation affected treatment time (Figure 4-15). As elevation increased, treatment time decreased. This seems counter-intuitive as physical exertion is more difficult in higher elevations. However, as elevation increased weed canopy cover decreased, therefore decreasing treatment time.

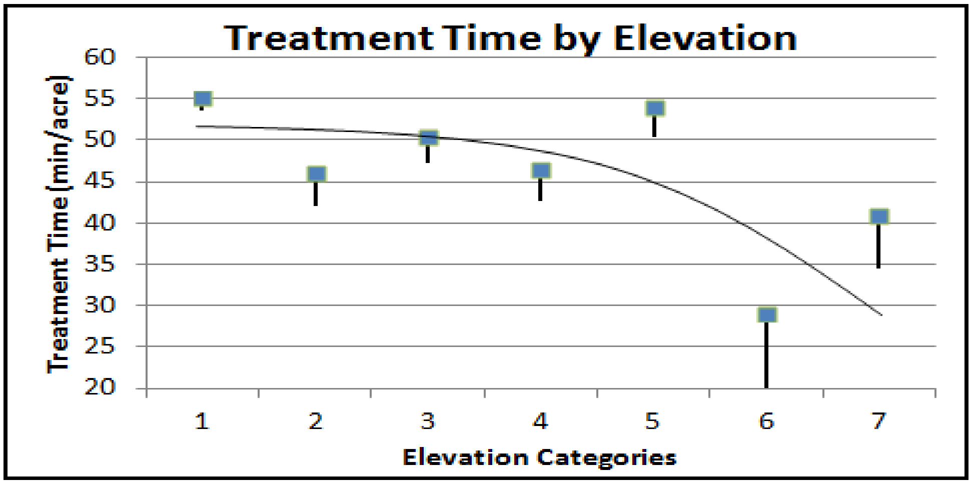

Figure 4-15. Treatment Time vs. elevation (means and standard errors). Elevation categories: 1. 4900-5500 ft, (1500-1675 meters); 2. 5500-6000 ft (1675-1830 meters)….6. 7500-8000 ft (2285-2440 meters); 7. >8000-8400 ft (2440-2560 meters).

Model 1 vs. Model 2

Treatment Time. Separating Treatment Time (T_t) and Rest (R_t) improved the treatment time fit based on the R^2 values. (0.6130 to 0.6876, Table 4-2 & Table 4-4).

Rest. Rest (Rt) was not explained well by the variables (R^2= 0.1174). In 2014 R_t activities were logged in the field to better understand why this was the case. Activity logs were recorded during treatment on two different days and sites for a total of 10 rests stops in 260 minutes (Table 4-5). One reasons for rest stops included backpack refill, which was not included in treatment time. Other activities that were included in treatment and rest time were a bathroom break, staff map orientation, phone calls to coordinate with the crew and office, taking monitoring pictures, switching the weed species designation on the “Smart” wand, and resetting the wand reset due to an applicator fall. Other possible reasons for a stop that were not experienced in this logging period may be equipment repair, client coordination or personal time such as a receiving or making a phone call or stopping to watch wildlife. Surprisingly, none of the logged stops were actual “rest,” or related to fatigue recovery even though the treatment areas were high weed canopy cover, and moderate to high slopes. This may be why separating the Treatment Time (T_t) and Rest (R_t) improved the treatment time fit. R_t appears to be comprised primarily of activities not largely affected by the hypothesized variables (D, LC,S,V, or UD). Therefore, when those activities are removed from total treatment time by subtracting R_t, there is a better fit with T_t to the hypothesized variables. Using Model 2 may clarify variable affects, but it is not useful to calculate an accurate treatment time estimate. Model 1 was therefore used to create the treatment time model.

Table 4-5. Activities during rest. The following activities were logged in 2014 during treatment on four different days and sites for a total of 14 rests stops in for 35 minutes in 1170 minutes of treatment time (3%). Additional possible reasons for treatment stops were added. The majority of these stops were not directly related to fatigue recovery.

Logged and Possible Activities During Stops		
Activity	Minutes	# of Stops
bathroom break	1	1
equipment repair/adjustment	4	1
SSW reset/change	5	2
transfer herbicide	2	1
orientation/map check	2	2
personal time	1	1
phone: client coordination	0	0
phone: crew coordination	7	3
phone: office coordination	3	2
communicate with public	10	1
rest	0	0
total stop time	35	14

*backpack refill time was not calculated into Total Treatment Time (T_{Tot})

Final Treatment Time Model

The final treatment time model was calculated using Model 1:

$$\mathbf{T_{Tot} \sim \mathit{f}(CC+LC+S+V+UD+O)}$$

The treatment time model summary is shown in Table 4-6.

Table 4-6 Model summary.

Model Summary				
Coefficients	Categories	**Estimate	Std. Er	P-value
*Intercept		-3.90	3.64	0.28393
CC 2	5.0 - <20%	21.34	1.07	< 2e-16
CC 3	20 - <50%	57.25	1.28	< 2e-16
CC 4	50 - <90%	126.74	1.98	< 2e-16
CC 5	>90%	199.80	3.00	< 2e-16
S 2	5 to <10°,	7.94	1.30	9.98E-10
S 3	10 to <20°	17.72	1.41	< 2e-16
S 4	20 to <25°	27.25	1.94	< 2e-16
S 5	25 to <35°,	24.61	1.88	< 2e-16
S 6	>35°	30.86	3.17	< 2e-16
LC 2	1.5-3.0 ft. (0.5-1.0 m)	11.15	2.12	1.42E-07
LC 3	>3.0 ft. (1.0 m)	36.99	3.18	< 2e-16
V 2	11-20 ft. (3-6 m)	16.34	3.42	1.74E-06
V 3	21-40 ft. (6-12 m)	10.50	3.46	0.00244
V 4	>40 feet (12 m)	6.93	3.44	0.04383
UD 1	Not efficient	19.42	1.23	< 2e-16

*Intercept: CC=0 - <5.0%, S=0 to <5°, LC=0-1.5 ft. (0 to 0.5 m), V=0-10 ft, (0-3 m), UD 0= Efficient

**Estimate in seconds per 882 ft^2 area

Due to the complexity of the model, the results were put in a table. A sample of the table is shown below and is calculated in acres per hour (Table 4-7). The full table is found in Appendix A. The dependent variables are canopy cover (Den), slope (Slp), land cover (LC), visibility (Vis) and up/down proportion efficiency (UpDn). The acre per hour fit (Fit), lower (Lwr) and upper (Upr) levels are shown. The one sided variation (Var) is also given to show the 95% confidence interval for the fit at each group of variables. The variable categories and descriptions are shown in Figure 3-8 and in Table 4-6.

Table 4-7. Wildland weed treatment time model table. The dependent variables are canopy cover (Den), slope (Slp), land cover (LC), visibility (Vis) and up/down proportion efficiency (UpDn). The acre per hour fit (Fit), lower (Lwr) and upper (Upr) levels are shown. The one sided variation (Var) is also given to show the 95% confidence interval for the fit at each group of variables. The full table, variable categories and descriptions are in Appendix A. Wildland Weed Treatment Time Model- Full Table.

#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var	#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var
181	1	1	1	2	0	4.84	5.04	4.63	0.04	361	1	1	1	3	0	5.45	5.67	5.26	0.04
182	1	1	2	2	0	3.91	4.18	3.64	0.07	362	1	1	2	3	0	4.4	4.71	4.11	0.07
183	1	1	3	2	0	3.03	3.34	2.74	0.1	363	1	1	3	3	0	3.41	3.77	3.1	0.09
184	1	1	1	2	1	3.12	3.23	3.02	0.03	364	1	1	1	3	1	3.51	3.64	3.41	0.03
185	1	1	2	2	1	2.53	2.7	2.37	0.06	365	1	1	2	3	1	2.84	3.05	2.67	0.06
186	1	1	3	2	1	1.97	2.17	1.79	0.09	366	1	1	3	3	1	2.21	2.44	2.02	0.09
187	1	2	1	2	0	4.11	4.27	3.93	0.04	367	1	2	1	3	0	4.63	4.81	4.46	0.04
188	1	2	2	2	0	3.31	3.55	3.08	0.07	368	1	2	2	3	0	3.73	4.02	3.46	0.07
189	1	2	3	2	0	2.57	2.83	2.33	0.09	369	1	2	3	3	0	2.89	3.19	2.63	0.09
190	1	2	1	2	1	2.66	2.77	2.55	0.04	370	1	2	1	3	1	2.98	3.11	2.87	0.04
191	1	2	2	2	1	2.16	2.31	2.01	0.07	371	1	2	2	3	1	2.42	2.6	2.25	0.07
192	1	2	3	2	1	1.68	1.85	1.52	0.09	372	1	2	3	3	1	1.89	2.08	1.71	0.09
193	1	3	1	2	0	3.34	3.46	3.23	0.03	373	1	3	1	3	0	3.77	3.89	3.65	0.03
194	1	3	2	2	0	2.71	2.89	2.53	0.07	374	1	3	2	3	0	3.05	3.26	2.84	0.07
195	1	3	3	2	0	2.11	2.32	1.92	0.09	375	1	3	3	3	0	2.37	2.6	2.16	0.09
196	1	3	1	2	1	2.18	2.28	2.08	0.05	376	1	3	1	3	1	2.44	2.56	2.33	0.04
197	1	3	2	2	1	1.77	1.9	1.64	0.07	377	1	3	2	3	1	1.99	2.14	1.84	0.08
198	1	3	3	2	1	1.38	1.52	1.25	0.09	378	1	3	3	3	1	1.55	1.71	1.4	0.09

Treatment Time Calculation Example. An example of treatment time calculation using Table 4-7 is as follows:

Bidding for the treatment of a 400 acre mountain side with a low canopy cover (Den, category 1- 0-<5%) dalmatian toadflax infestation. The area slope is 15 degrees

(Slp, category 3- 10 to 20 degrees) and it has grass and scattered brush that would be low resistance land cover (LC, category 1). The dalmatian toadflax has high visibility (Vis, category 3). The crews have been trained to work efficiently on slopes (UpDn, category 0). Using the categorical information, a contractor could search the index table and find the appropriate fit. In this example, the fit appears on line #373 in Table 4-7. The fit on that line is 3.77 acres per hour, with a 95% probability that it would be between 3.65 (lwr (lower)) and 3.89 (upr (upper)) acres per hour. The area can be treated in 106 hours (400 acres ÷ 3.77 acres per hour) (103 lower, 110 upper). If the going rate for application is $80 per hour, the cost would be $8480 ($8240 lower, $8800 upper).

Conclusion

The primary influence of the model is due to weed canopy cover, with smaller impacts by other variables. If canopy cover, slope, land cover and weed visibility information can be obtained for a weed control project, the model can be used. The model can: 1) establish a treatment time standard for land managers and contractors; 2) assist contractors and land managers to more precisely plan and manage limited resources; and 3) justify costs when seeking funding, during planning and when accounting to funding sources.

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APPENDICES

Appendix A. Wildland Weed Treatment Time Model- Full Table

Appendix A-1. Page 1 of 6.

#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var	#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var
1	1	1	1	1	0	6.7	7.46	5.99	0.11	271	3	4	1	2	0	0.87	0.92	0.82	0.05
2	1	1	2	1	0	5.37	5.99	4.81	0.11	272	3	4	2	2	0	0.71	0.76	0.66	0.07
3	1	1	3	1	0	4.15	4.78	3.6	0.13	273	3	4	3	2	0	0.56	0.62	0.5	0.1
4	1	1	1	1	1	4.27	4.75	3.87	0.1	274	3	4	1	2	1	0.57	0.61	0.54	0.06
5	1	1	2	1	1	3.46	3.85	3.11	0.1	275	3	4	2	2	1	0.47	0.5	0.43	0.07
6	1	1	3	1	1	2.69	3.08	2.34	0.13	276	3	4	3	2	1	0.37	0.41	0.33	0.1
7	1	2	1	1	0	5.62	6.25	5.08	0.1	277	3	5	1	2	0	0.91	0.96	0.86	0.05
8	1	2	2	1	0	4.54	5.04	4.08	0.1	278	3	5	2	2	0	0.74	0.8	0.69	0.07
9	1	2	3	1	0	3.51	4.04	3.06	0.13	279	3	5	3	2	0	0.58	0.64	0.53	0.1
10	1	2	1	1	1	3.64	4.04	3.26	0.1	280	3	5	1	2	1	0.6	0.64	0.56	0.06
11	1	2	2	1	1	2.93	3.26	2.64	0.1	281	3	5	2	2	1	0.49	0.53	0.45	0.07
12	1	2	3	1	1	2.28	2.62	1.99	0.13	282	3	5	3	2	1	0.38	0.42	0.35	0.1
13	1	3	1	1	0	4.57	5.08	4.13	0.1	283	3	6	1	2	0	0.74	0.8	0.67	0.08
14	1	3	2	1	0	3.69	4.11	3.34	0.1	284	3	6	2	2	0	0.6	0.66	0.54	0.1
15	1	3	3	1	0	2.87	3.28	2.51	0.12	285	3	6	3	2	0	0.47	0.53	0.42	0.11
16	1	3	1	1	1	2.96	3.29	2.67	0.1	286	3	6	1	2	1	0.48	0.53	0.44	0.09
17	1	3	2	1	1	2.4	2.67	2.16	0.1	287	3	6	2	2	1	0.39	0.44	0.36	0.1
18	1	3	3	1	1	1.87	2.14	1.63	0.13	288	3	6	3	2	1	0.31	0.35	0.27	0.12
19	1	4	1	1	0	4.02	4.46	3.64	0.09	289	4	1	1	2	0	0.78	0.83	0.73	0.07
20	1	4	2	1	0	3.25	3.6	2.93	0.1	290	4	1	2	2	0	0.63	0.69	0.58	0.08
21	1	4	3	1	0	2.53	2.9	2.21	0.13	291	4	1	3	2	0	0.5	0.55	0.45	0.1
22	1	4	1	1	1	2.61	2.91	2.34	0.1	292	4	1	1	2	1	0.51	0.54	0.48	0.05
23	1	4	2	1	1	2.12	2.36	1.9	0.1	293	4	1	2	2	1	0.42	0.45	0.39	0.07
24	1	4	3	1	1	1.65	1.9	1.44	0.13	294	4	1	3	2	1	0.33	0.36	0.3	0.1
25	1	5	1	1	0	4.2	4.68	3.79	0.1	295	4	2	1	2	0	0.66	0.71	0.62	0.06
26	1	5	2	1	0	3.4	3.79	3.06	0.1	296	4	2	2	2	0	0.54	0.59	0.5	0.08
27	1	5	3	1	0	2.65	3.03	2.31	0.13	297	4	2	3	2	0	0.42	0.47	0.38	0.1
28	1	5	1	1	1	2.73	3.05	2.44	0.1	298	4	2	1	2	1	0.44	0.46	0.41	0.06
29	1	5	2	1	1	2.21	2.47	1.98	0.11	299	4	2	2	2	1	0.36	0.38	0.33	0.07
30	1	5	3	1	1	1.73	1.99	1.5	0.13	300	4	2	3	2	1	0.28	0.31	0.25	0.1
31	1	6	1	1	0	3.37	3.83	2.98	0.11	301	4	3	1	2	0	0.55	0.58	0.51	0.06
32	1	6	2	1	0	2.73	3.1	2.41	0.12	302	4	3	2	2	0	0.45	0.48	0.41	0.08
33	1	6	3	1	0	2.12	2.47	1.83	0.14	303	4	3	3	2	0	0.35	0.39	0.31	0.1
34	1	6	1	1	1	2.19	2.49	1.93	0.12	304	4	3	1	2	1	0.36	0.38	0.34	0.06
35	1	6	2	1	1	1.78	2.03	1.56	0.12	305	4	3	2	2	1	0.29	0.32	0.27	0.08
36	1	6	3	1	1	1.39	1.62	1.19	0.14	306	4	3	3	2	1	0.23	0.26	0.21	0.1
37	2	1	1	1	0	3.45	3.83	3.1	0.1	307	4	4	1	2	0	0.48	0.52	0.45	0.07
38	2	1	2	1	0	2.79	3.1	2.5	0.1	308	4	4	2	2	0	0.39	0.43	0.36	0.08
39	2	1	3	1	0	2.17	2.49	1.89	0.13	309	4	4	3	2	0	0.31	0.34	0.28	0.1
40	2	1	1	1	1	2.24	2.48	2.02	0.1	310	4	4	1	2	1	0.32	0.34	0.3	0.07
41	2	1	2	1	1	1.82	2.01	1.64	0.1	311	4	4	2	2	1	0.26	0.28	0.24	0.08
42	2	1	3	1	1	1.42	1.62	1.24	0.13	312	4	4	3	2	1	0.2	0.23	0.18	0.1
43	2	2	1	1	0	2.92	3.25	2.63	0.1	313	4	5	1	2	0	0.5	0.54	0.47	0.07
44	2	2	2	1	0	2.37	2.64	2.13	0.1	314	4	5	2	2	0	0.41	0.45	0.38	0.08
45	2	2	3	1	0	1.85	2.12	1.61	0.13	315	4	5	3	2	0	0.32	0.36	0.29	0.1
46	2	2	1	1	1	1.91	2.11	1.72	0.1	316	4	5	1	2	1	0.33	0.36	0.31	0.07

Appendix A-2. Page 2 of 6.

#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var	#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var
47	2	2	2	1	1	1.55	1.72	1.39	0.1	317	4	5	2	2	1	0.27	0.3	0.25	0.08
48	2	2	3	1	1	1.21	1.38	1.06	0.13	318	4	5	3	2	1	0.21	0.24	0.19	0.1
49	2	3	1	1	0	2.4	2.65	2.17	0.09	319	4	6	1	2	0	0.41	0.45	0.37	0.09
50	2	3	2	1	0	1.94	2.15	1.75	0.1	320	4	6	2	2	0	0.33	0.37	0.3	0.1
51	2	3	3	1	0	1.52	1.73	1.33	0.12	321	4	6	3	2	0	0.26	0.3	0.23	0.12
52	2	3	1	1	1	1.56	1.73	1.41	0.1	322	4	6	1	2	1	0.27	0.3	0.24	0.1
53	2	3	2	1	1	1.27	1.41	1.15	0.1	323	4	6	2	2	1	0.22	0.25	0.2	0.11
54	2	3	3	1	1	0.99	1.14	0.87	0.13	324	4	6	3	2	1	0.17	0.2	0.15	0.12
55	2	4	1	1	0	2.11	2.33	1.9	0.1	325	5	1	1	2	0	0.53	0.58	0.48	0.09
56	2	4	2	1	0	1.71	1.9	1.55	0.1	326	5	1	2	2	0	0.43	0.48	0.39	0.1
57	2	4	3	1	0	1.34	1.53	1.17	0.13	327	5	1	3	2	0	0.34	0.39	0.3	0.12
58	2	4	1	1	1	1.38	1.54	1.24	0.1	328	5	1	1	2	1	0.35	0.38	0.32	0.08
59	2	4	2	1	1	1.12	1.25	1.01	0.1	329	5	1	2	2	1	0.29	0.31	0.26	0.09
60	2	4	3	1	1	0.88	1.01	0.77	0.13	330	5	1	3	2	1	0.22	0.25	0.2	0.11
61	2	5	1	1	0	2.21	2.44	1.99	0.1	331	5	2	1	2	0	0.45	0.5	0.41	0.09
62	2	5	2	1	0	1.79	1.99	1.61	0.1	332	5	2	2	2	0	0.37	0.41	0.33	0.1
63	2	5	3	1	0	1.4	1.6	1.22	0.13	333	5	2	3	2	0	0.29	0.33	0.26	0.12
64	2	5	1	1	1	1.44	1.61	1.3	0.1	334	5	2	1	2	1	0.3	0.33	0.27	0.08
65	2	5	2	1	1	1.17	1.31	1.05	0.1	335	5	2	2	2	1	0.24	0.27	0.22	0.09
66	2	5	3	1	1	0.92	1.05	0.8	0.13	336	5	2	3	2	1	0.19	0.22	0.17	0.11
67	2	6	1	1	0	1.77	2.01	1.57	0.11	337	5	3	1	2	0	0.37	0.41	0.34	0.08
68	2	6	2	1	0	1.44	1.63	1.28	0.12	338	5	3	2	2	0	0.3	0.34	0.28	0.1
69	2	6	3	1	0	1.13	1.31	0.97	0.14	339	5	3	3	2	0	0.24	0.27	0.21	0.11
70	2	6	1	1	1	1.16	1.32	1.02	0.12	340	5	3	1	2	1	0.25	0.27	0.23	0.08
71	2	6	2	1	1	0.95	1.08	0.83	0.12	341	5	3	2	2	1	0.2	0.22	0.18	0.09
72	2	6	3	1	1	0.74	0.86	0.64	0.14	342	5	3	3	2	1	0.16	0.18	0.14	0.11
73	3	1	1	1	0	1.91	2.12	1.72	0.1	343	5	4	1	2	0	0.33	0.36	0.3	0.09
74	3	1	2	1	0	1.55	1.73	1.4	0.1	344	5	4	2	2	0	0.27	0.3	0.24	0.1
75	3	1	3	1	0	1.21	1.39	1.06	0.13	345	5	4	3	2	0	0.21	0.24	0.19	0.12
76	3	1	1	1	1	1.25	1.38	1.13	0.09	346	5	4	1	2	1	0.22	0.24	0.2	0.09
77	3	1	2	1	1	1.02	1.13	0.92	0.09	347	5	4	2	2	1	0.18	0.2	0.16	0.1
78	3	1	3	1	1	0.8	0.91	0.7	0.12	348	5	4	3	2	1	0.14	0.16	0.12	0.12
79	3	2	1	1	0	1.63	1.81	1.47	0.1	349	5	5	1	2	0	0.35	0.38	0.31	0.09
80	3	2	2	1	0	1.32	1.47	1.19	0.1	350	5	5	2	2	0	0.28	0.31	0.25	0.1
81	3	2	3	1	0	1.04	1.18	0.9	0.13	351	5	5	3	2	0	0.22	0.25	0.19	0.12
82	3	2	1	1	1	1.07	1.18	0.96	0.1	352	5	5	1	2	1	0.23	0.25	0.21	0.09
83	3	2	2	1	1	0.87	0.96	0.78	0.1	353	5	5	2	2	1	0.19	0.21	0.17	0.1
84	3	2	3	1	1	0.68	0.78	0.6	0.13	354	5	5	3	2	1	0.15	0.17	0.13	0.12
85	3	3	1	1	0	1.34	1.48	1.21	0.09	355	5	6	1	2	0	0.28	0.31	0.25	0.11
86	3	3	2	1	0	1.09	1.2	0.98	0.1	356	5	6	2	2	0	0.23	0.26	0.2	0.12
87	3	3	3	1	0	0.85	0.97	0.75	0.12	357	5	6	3	2	0	0.18	0.21	0.16	0.13
88	3	3	1	1	1	0.88	0.97	0.79	0.1	358	5	6	1	2	1	0.18	0.21	0.16	0.11
89	3	3	2	1	1	0.72	0.79	0.65	0.1	359	5	6	2	2	1	0.15	0.17	0.13	0.12
90	3	3	3	1	1	0.56	0.64	0.49	0.12	360	5	6	3	2	1	0.12	0.14	0.1	0.13
91	3	4	1	1	0	1.18	1.31	1.07	0.1	361	1	1	1	3	0	5.45	5.67	5.26	0.04
92	3	4	2	1	0	0.96	1.06	0.87	0.1	362	1	1	2	3	0	4.4	4.71	4.11	0.07

Appendix A-3. Page 3 of 6.

#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var	#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var
93	3	4	3	1	0	0.75	0.86	0.66	0.12	363	1	1	3	3	0	3.41	3.77	3.1	0.09
94	3	4	1	1	1	0.78	0.86	0.7	0.1	364	1	1	1	3	1	3.51	3.64	3.41	0.03
95	3	4	2	1	1	0.63	0.7	0.57	0.1	365	1	1	2	3	1	2.84	3.05	2.67	0.06
96	3	4	3	1	1	0.5	0.57	0.43	0.13	366	1	1	3	3	1	2.21	2.44	2.02	0.09
97	3	5	1	1	0	1.23	1.37	1.11	0.1	367	1	2	1	3	0	4.63	4.81	4.46	0.04
98	3	5	2	1	0	1	1.11	0.91	0.1	368	1	2	2	3	0	3.73	4.02	3.46	0.07
99	3	5	3	1	0	0.78	0.9	0.69	0.13	369	1	2	3	3	0	2.89	3.19	2.63	0.09
100	3	5	1	1	1	0.81	0.9	0.73	0.1	370	1	2	1	3	1	2.98	3.11	2.87	0.04
101	3	5	2	1	1	0.66	0.73	0.59	0.1	371	1	2	2	3	1	2.42	2.6	2.25	0.07
102	3	5	3	1	1	0.52	0.59	0.45	0.13	372	1	2	3	3	1	1.89	2.08	1.71	0.09
103	3	6	1	1	0	1	1.13	0.88	0.12	373	1	3	1	3	0	3.77	3.89	3.65	0.03
104	3	6	2	1	0	0.81	0.92	0.72	0.12	374	1	3	2	3	0	3.05	3.26	2.84	0.07
105	3	6	3	1	0	0.63	0.74	0.55	0.14	375	1	3	3	3	0	2.37	2.6	2.16	0.09
106	3	6	1	1	1	0.65	0.74	0.58	0.12	376	1	3	1	3	1	2.44	2.56	2.33	0.04
107	3	6	2	1	1	0.53	0.6	0.47	0.12	377	1	3	2	3	1	1.99	2.14	1.84	0.08
108	3	6	3	1	1	0.42	0.49	0.36	0.14	378	1	3	3	3	1	1.55	1.71	1.4	0.09
109	4	1	1	1	0	1.05	1.18	0.94	0.11	379	1	4	1	3	0	3.31	3.48	3.16	0.04
110	4	1	2	1	0	0.86	0.96	0.77	0.11	380	1	4	2	3	0	2.68	2.89	2.49	0.07
111	4	1	3	1	0	0.67	0.77	0.58	0.13	381	1	4	3	3	0	2.09	2.31	1.89	0.1
112	4	1	1	1	1	0.69	0.77	0.62	0.1	382	1	4	1	3	1	2.16	2.29	2.03	0.06
113	4	1	2	1	1	0.56	0.63	0.51	0.1	383	1	4	2	3	1	1.75	1.9	1.61	0.08
114	4	1	3	1	1	0.44	0.51	0.39	0.13	384	1	4	3	3	1	1.37	1.52	1.23	0.1
115	4	2	1	1	0	0.9	1.01	0.8	0.11	385	1	5	1	3	0	3.46	3.62	3.31	0.05
116	4	2	2	1	0	0.73	0.82	0.65	0.1	386	1	5	2	3	0	2.8	3.02	2.6	0.07
117	4	2	3	1	0	0.57	0.66	0.5	0.13	387	1	5	3	3	0	2.18	2.4	1.98	0.09
118	4	2	1	1	1	0.59	0.66	0.53	0.1	388	1	5	1	3	1	2.26	2.39	2.12	0.06
119	4	2	2	1	1	0.48	0.54	0.43	0.1	389	1	5	2	3	1	1.83	1.99	1.68	0.08
120	4	2	3	1	1	0.38	0.43	0.33	0.13	390	1	5	3	3	1	1.43	1.59	1.29	0.1
121	4	3	1	1	0	0.74	0.82	0.66	0.1	391	1	6	1	3	0	2.78	3.03	2.56	0.08
122	4	3	2	1	0	0.6	0.67	0.54	0.1	392	1	6	2	3	0	2.26	2.5	2.03	0.1
123	4	3	3	1	0	0.47	0.54	0.41	0.13	393	1	6	3	3	0	1.76	1.98	1.56	0.11
124	4	3	1	1	1	0.49	0.54	0.44	0.1	394	1	6	1	3	1	1.81	1.99	1.65	0.09
125	4	3	2	1	1	0.4	0.44	0.36	0.1	395	1	6	2	3	1	1.47	1.65	1.32	0.1
126	4	3	3	1	1	0.31	0.36	0.27	0.13	396	1	6	3	3	1	1.15	1.3	1.02	0.12
127	4	4	1	1	0	0.65	0.73	0.59	0.1	397	2	1	1	3	0	2.84	2.96	2.73	0.04
128	4	4	2	1	0	0.53	0.59	0.48	0.1	398	2	1	2	3	0	2.3	2.47	2.14	0.07
129	4	4	3	1	0	0.42	0.48	0.36	0.13	399	2	1	3	3	0	1.79	1.98	1.63	0.09
130	4	4	1	1	1	0.43	0.48	0.39	0.1	400	2	1	1	3	1	1.85	1.91	1.8	0.03
131	4	4	2	1	1	0.35	0.39	0.31	0.1	401	2	1	2	3	1	1.5	1.61	1.41	0.06
132	4	4	3	1	1	0.28	0.32	0.24	0.13	402	2	1	3	3	1	1.17	1.29	1.07	0.09
133	4	5	1	1	0	0.68	0.76	0.61	0.1	403	2	2	1	3	0	2.41	2.51	2.32	0.04
134	4	5	2	1	0	0.56	0.62	0.5	0.1	404	2	2	2	3	0	1.96	2.11	1.82	0.07
135	4	5	3	1	0	0.44	0.5	0.38	0.13	405	2	2	3	3	0	1.53	1.68	1.39	0.09
136	4	5	1	1	1	0.45	0.5	0.4	0.11	406	2	2	1	3	1	1.58	1.64	1.52	0.04
137	4	5	2	1	1	0.37	0.41	0.33	0.1	407	2	2	2	3	1	1.28	1.38	1.19	0.07
138	4	5	3	1	1	0.29	0.33	0.25	0.13	408	2	2	3	3	1	1	1.1	0.91	0.09

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#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var	#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var
139	4	6	1	1	0	0.55	0.63	0.48	0.12	409	2	3	1	3	0	1.98	2.05	1.91	0.03
140	4	6	2	1	0	0.45	0.51	0.4	0.12	410	2	3	2	3	0	1.61	1.72	1.5	0.07
141	4	6	3	1	0	0.35	0.41	0.3	0.14	411	2	3	3	3	0	1.25	1.38	1.14	0.09
142	4	6	1	1	1	0.36	0.41	0.32	0.12	412	2	3	1	3	1	1.29	1.35	1.24	0.04
143	4	6	2	1	1	0.3	0.34	0.26	0.12	413	2	3	2	3	1	1.05	1.13	0.98	0.07
144	4	6	3	1	1	0.23	0.27	0.2	0.14	414	2	3	3	3	1	0.82	0.91	0.75	0.09
145	5	1	1	1	0	0.72	0.82	0.63	0.12	415	2	4	1	3	0	1.74	1.83	1.66	0.05
146	5	1	2	1	0	0.59	0.66	0.52	0.12	416	2	4	2	3	0	1.42	1.53	1.31	0.07
147	5	1	3	1	0	0.46	0.54	0.39	0.14	417	2	4	3	3	0	1.11	1.22	1	0.09
148	5	1	1	1	1	0.47	0.54	0.42	0.12	418	2	4	1	3	1	1.14	1.21	1.08	0.06
149	5	1	2	1	1	0.39	0.44	0.34	0.11	419	2	4	2	3	1	0.93	1.01	0.86	0.08
150	5	1	3	1	1	0.3	0.35	0.26	0.14	420	2	4	3	3	1	0.73	0.81	0.66	0.1
151	5	2	1	1	0	0.61	0.7	0.54	0.12	421	2	5	1	3	0	1.82	1.9	1.74	0.04
152	5	2	2	1	0	0.5	0.57	0.44	0.12	422	2	5	2	3	0	1.48	1.59	1.38	0.07
153	5	2	3	1	0	0.39	0.46	0.34	0.14	423	2	5	3	3	0	1.16	1.27	1.05	0.09
154	5	2	1	1	1	0.4	0.46	0.36	0.12	424	2	5	1	3	1	1.19	1.26	1.13	0.05
155	5	2	2	1	1	0.33	0.37	0.29	0.12	425	2	5	2	3	1	0.97	1.05	0.9	0.08
156	5	2	3	1	1	0.26	0.3	0.22	0.14	426	2	5	3	3	1	0.76	0.84	0.69	0.1
157	5	3	1	1	0	0.51	0.57	0.45	0.12	427	2	6	1	3	0	1.47	1.6	1.35	0.08
158	5	3	2	1	0	0.41	0.47	0.36	0.12	428	2	6	2	3	0	1.19	1.32	1.08	0.1
159	5	3	3	1	0	0.32	0.37	0.28	0.14	429	2	6	3	3	0	0.93	1.05	0.83	0.11
160	5	3	1	1	1	0.33	0.38	0.29	0.12	430	2	6	1	3	1	0.96	1.06	0.88	0.09
161	5	3	2	1	1	0.27	0.31	0.24	0.12	431	2	6	2	3	1	0.78	0.87	0.7	0.1
162	5	3	3	1	1	0.21	0.25	0.18	0.14	432	2	6	3	3	1	0.61	0.69	0.54	0.11
163	5	4	1	1	0	0.45	0.51	0.39	0.12	433	3	1	1	3	0	1.58	1.66	1.51	0.05
164	5	4	2	1	0	0.36	0.41	0.32	0.11	434	3	1	2	3	0	1.29	1.38	1.19	0.07
165	5	4	3	1	0	0.29	0.33	0.25	0.14	435	3	1	3	3	0	1.01	1.11	0.91	0.09
166	5	4	1	1	1	0.29	0.33	0.26	0.12	436	3	1	1	3	1	1.04	1.07	1	0.03
167	5	4	2	1	1	0.24	0.27	0.21	0.12	437	3	1	2	3	1	0.84	0.9	0.79	0.06
168	5	4	3	1	1	0.19	0.22	0.16	0.14	438	3	1	3	3	1	0.66	0.73	0.6	0.09
169	5	5	1	1	0	0.47	0.53	0.41	0.12	439	3	2	1	3	0	1.35	1.41	1.29	0.04
170	5	5	2	1	0	0.38	0.43	0.34	0.12	440	3	2	2	3	0	1.1	1.18	1.02	0.07
171	5	5	3	1	0	0.3	0.35	0.26	0.14	441	3	2	3	3	0	0.86	0.95	0.78	0.09
172	5	5	1	1	1	0.31	0.35	0.27	0.12	442	3	2	1	3	1	0.88	0.92	0.85	0.04
173	5	5	2	1	1	0.25	0.28	0.22	0.12	443	3	2	2	3	1	0.72	0.77	0.67	0.07
174	5	5	3	1	1	0.2	0.23	0.17	0.14	444	3	2	3	3	1	0.56	0.62	0.51	0.09
175	5	6	1	1	0	0.38	0.44	0.33	0.13	445	3	3	1	3	0	1.11	1.15	1.06	0.04
176	5	6	2	1	0	0.31	0.35	0.27	0.13	446	3	3	2	3	0	0.9	0.97	0.84	0.07
177	5	6	3	1	0	0.24	0.28	0.2	0.15	447	3	3	3	3	0	0.71	0.78	0.64	0.09
178	5	6	1	1	1	0.25	0.29	0.22	0.13	448	3	3	1	3	1	0.73	0.76	0.7	0.04
179	5	6	2	1	1	0.2	0.23	0.18	0.13	449	3	3	2	3	1	0.59	0.64	0.55	0.07
180	5	6	3	1	1	0.16	0.19	0.14	0.15	450	3	3	3	3	1	0.46	0.51	0.42	0.09
181	1	1	1	2	0	4.84	5.04	4.63	0.04	451	3	4	1	3	0	0.98	1.03	0.93	0.05
182	1	1	2	2	0	3.91	4.18	3.64	0.07	452	3	4	2	3	0	0.8	0.86	0.74	0.07
183	1	1	3	2	0	3.03	3.34	2.74	0.1	453	3	4	3	3	0	0.62	0.69	0.56	0.09
184	1	1	1	2	1	3.12	3.23	3.02	0.03	454	3	4	1	3	1	0.64	0.68	0.61	0.06

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#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var	#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var
185	1	1	2	2	1	2.53	2.7	2.37	0.06	455	3	4	2	3	1	0.52	0.57	0.48	0.08
186	1	1	3	2	1	1.97	2.17	1.79	0.09	456	3	4	3	3	1	0.41	0.46	0.37	0.1
187	1	2	1	2	0	4.11	4.27	3.93	0.04	457	3	5	1	3	0	1.02	1.07	0.97	0.05
188	1	2	2	2	0	3.31	3.55	3.08	0.07	458	3	5	2	3	0	0.83	0.9	0.77	0.07
189	1	2	3	2	0	2.57	2.83	2.33	0.09	459	3	5	3	3	0	0.65	0.72	0.59	0.09
190	1	2	1	2	1	2.66	2.77	2.55	0.04	460	3	5	1	3	1	0.67	0.71	0.64	0.05
191	1	2	2	2	1	2.16	2.31	2.01	0.07	461	3	5	2	3	1	0.55	0.59	0.51	0.07
192	1	2	3	2	1	1.68	1.85	1.52	0.09	462	3	5	3	3	1	0.43	0.47	0.39	0.1
193	1	3	1	2	0	3.34	3.46	3.23	0.03	463	3	6	1	3	0	0.82	0.9	0.76	0.08
194	1	3	2	2	0	2.71	2.89	2.53	0.07	464	3	6	2	3	0	0.67	0.74	0.61	0.1
195	1	3	3	2	0	2.11	2.32	1.92	0.09	465	3	6	3	3	0	0.53	0.59	0.47	0.11
196	1	3	1	2	1	2.18	2.28	2.08	0.05	466	3	6	1	3	1	0.54	0.59	0.5	0.09
197	1	3	2	2	1	1.77	1.9	1.64	0.07	467	3	6	2	3	1	0.44	0.49	0.4	0.1
198	1	3	3	2	1	1.38	1.52	1.25	0.09	468	3	6	3	3	1	0.35	0.39	0.31	0.11
199	1	4	1	2	0	2.95	3.1	2.8	0.05	469	4	1	1	3	0	0.87	0.93	0.82	0.06
200	1	4	2	2	0	2.38	2.56	2.21	0.07	470	4	1	2	3	0	0.71	0.77	0.65	0.08
201	1	4	3	2	0	1.86	2.05	1.68	0.1	471	4	1	3	3	0	0.56	0.62	0.5	0.1
202	1	4	1	2	1	1.92	2.04	1.8	0.06	472	4	1	1	3	1	0.57	0.61	0.54	0.05
203	1	4	2	2	1	1.56	1.69	1.44	0.08	473	4	1	2	3	1	0.47	0.51	0.43	0.07
204	1	4	3	2	1	1.22	1.35	1.09	0.1	474	4	1	3	3	1	0.37	0.41	0.33	0.1
205	1	5	1	2	0	3.07	3.23	2.92	0.05	475	4	2	1	3	0	0.74	0.79	0.7	0.06
206	1	5	2	2	0	2.49	2.68	2.32	0.07	476	4	2	2	3	0	0.61	0.66	0.56	0.08
207	1	5	3	2	0	1.94	2.14	1.76	0.1	477	4	2	3	3	0	0.48	0.53	0.43	0.1
208	1	5	1	2	1	2	2.13	1.88	0.06	478	4	2	1	3	1	0.49	0.52	0.46	0.06
209	1	5	2	2	1	1.63	1.77	1.5	0.08	479	4	2	2	3	1	0.4	0.43	0.37	0.08
210	1	5	3	2	1	1.27	1.41	1.15	0.1	480	4	2	3	3	1	0.31	0.35	0.28	0.1
211	1	6	1	2	0	2.47	2.7	2.27	0.08	481	4	3	1	3	0	0.61	0.65	0.58	0.06
212	1	6	2	2	0	2	2.22	1.81	0.1	482	4	3	2	3	0	0.5	0.54	0.46	0.08
213	1	6	3	2	0	1.56	1.77	1.39	0.11	483	4	3	3	3	0	0.39	0.43	0.35	0.1
214	1	6	1	2	1	1.61	1.77	1.47	0.09	484	4	3	1	3	1	0.4	0.43	0.38	0.06
215	1	6	2	2	1	1.31	1.46	1.18	0.1	485	4	3	2	3	1	0.33	0.36	0.3	0.08
216	1	6	3	2	1	1.03	1.16	0.91	0.12	486	4	3	3	3	1	0.26	0.29	0.23	0.1
217	2	1	1	2	0	2.52	2.64	2.41	0.04	487	4	4	1	3	0	0.54	0.58	0.51	0.06
218	2	1	2	2	0	2.05	2.19	1.91	0.07	488	4	4	2	3	0	0.44	0.48	0.41	0.08
219	2	1	3	2	0	1.6	1.77	1.44	0.09	489	4	4	3	3	0	0.35	0.39	0.31	0.1
220	2	1	1	2	1	1.65	1.71	1.59	0.03	490	4	4	1	3	1	0.36	0.38	0.33	0.07
221	2	1	2	2	1	1.34	1.43	1.26	0.06	491	4	4	2	3	1	0.29	0.32	0.27	0.08
222	2	1	3	2	1	1.05	1.15	0.95	0.09	492	4	4	3	3	1	0.23	0.25	0.2	0.1
223	2	2	1	2	0	2.14	2.24	2.05	0.04	493	4	5	1	3	0	0.57	0.6	0.53	0.06
224	2	2	2	2	0	1.74	1.87	1.62	0.07	494	4	5	2	3	0	0.46	0.5	0.42	0.08
225	2	2	3	2	0	1.36	1.5	1.23	0.09	495	4	5	3	3	0	0.36	0.4	0.33	0.1
226	2	2	1	2	1	1.4	1.46	1.35	0.04	496	4	5	1	3	1	0.37	0.4	0.35	0.07
227	2	2	2	2	1	1.14	1.22	1.07	0.07	497	4	5	2	3	1	0.3	0.33	0.28	0.08
228	2	2	3	2	1	0.89	0.98	0.81	0.09	498	4	5	3	3	1	0.24	0.27	0.21	0.1
229	2	3	1	2	0	1.76	1.83	1.7	0.04	499	4	6	1	3	0	0.46	0.5	0.42	0.09
230	2	3	2	2	0	1.43	1.53	1.34	0.07	500	4	6	2	3	0	0.37	0.42	0.33	0.1

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#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var	#	Den	Slp	LC	Vis	UpDn	Fit	Lwr	Upr	Var
231	2	3	3	2	0	1.12	1.23	1.02	0.09	501	4	6	3	3	0	0.29	0.33	0.26	0.12
232	2	3	1	2	1	1.15	1.21	1.1	0.04	502	4	6	1	3	1	0.3	0.33	0.27	0.09
233	2	3	2	2	1	0.94	1.01	0.87	0.07	503	4	6	2	3	1	0.25	0.28	0.22	0.11
234	2	3	3	2	1	0.73	0.81	0.67	0.09	504	4	6	3	3	1	0.19	0.22	0.17	0.12
235	2	4	1	2	0	1.55	1.63	1.47	0.05	505	5	1	1	3	0	0.6	0.65	0.54	0.09
236	2	4	2	2	0	1.26	1.36	1.17	0.07	506	5	1	2	3	0	0.49	0.54	0.44	0.1
237	2	4	3	2	0	0.99	1.09	0.89	0.1	507	5	1	3	3	0	0.38	0.43	0.34	0.12
238	2	4	1	2	1	1.02	1.08	0.96	0.06	508	5	1	1	3	1	0.39	0.43	0.36	0.08
239	2	4	2	2	1	0.83	0.9	0.77	0.08	509	5	1	2	3	1	0.32	0.35	0.29	0.09
240	2	4	3	2	1	0.65	0.72	0.58	0.1	510	5	1	3	3	1	0.25	0.28	0.22	0.11
241	2	5	1	2	0	1.62	1.7	1.55	0.05	511	5	2	1	3	0	0.51	0.56	0.47	0.08
242	2	5	2	2	0	1.32	1.42	1.23	0.07	512	5	2	2	3	0	0.41	0.46	0.37	0.1
243	2	5	3	2	0	1.03	1.14	0.93	0.09	513	5	2	3	3	0	0.33	0.37	0.29	0.12
244	2	5	1	2	1	1.06	1.13	1	0.06	514	5	2	1	3	1	0.34	0.37	0.31	0.08
245	2	5	2	2	1	0.87	0.94	0.8	0.07	515	5	2	2	3	1	0.27	0.3	0.25	0.09
246	2	5	3	2	1	0.68	0.75	0.61	0.1	516	5	2	3	3	1	0.21	0.24	0.19	0.11
247	2	6	1	2	0	1.31	1.43	1.2	0.08	517	5	3	1	3	0	0.42	0.46	0.38	0.08
248	2	6	2	2	0	1.06	1.18	0.96	0.1	518	5	3	2	3	0	0.34	0.38	0.31	0.1
249	2	6	3	2	0	0.83	0.94	0.74	0.11	519	5	3	3	3	0	0.27	0.3	0.24	0.11
250	2	6	1	2	1	0.86	0.94	0.78	0.09	520	5	3	1	3	1	0.28	0.3	0.25	0.08
251	2	6	2	2	1	0.7	0.78	0.63	0.1	521	5	3	2	3	1	0.23	0.25	0.2	0.1
252	2	6	3	2	1	0.55	0.62	0.48	0.12	522	5	3	3	3	1	0.18	0.2	0.16	0.11
253	3	1	1	2	0	1.41	1.48	1.34	0.05	523	5	4	1	3	0	0.37	0.41	0.34	0.09
254	3	1	2	2	0	1.15	1.23	1.07	0.07	524	5	4	2	3	0	0.3	0.34	0.27	0.1
255	3	1	3	2	0	0.9	0.99	0.81	0.1	525	5	4	3	3	0	0.24	0.27	0.21	0.12
256	3	1	1	2	1	0.92	0.96	0.89	0.04	526	5	4	1	3	1	0.24	0.27	0.22	0.09
257	3	1	2	2	1	0.75	0.8	0.71	0.06	527	5	4	2	3	1	0.2	0.22	0.18	0.1
258	3	1	3	2	1	0.59	0.65	0.54	0.09	528	5	4	3	3	1	0.16	0.18	0.14	0.12
259	3	2	1	2	0	1.2	1.26	1.14	0.05	529	5	5	1	3	0	0.39	0.42	0.35	0.09
260	3	2	2	2	0	0.98	1.05	0.91	0.07	530	5	5	2	3	0	0.32	0.35	0.28	0.1
261	3	2	3	2	0	0.76	0.84	0.69	0.09	531	5	5	3	3	0	0.25	0.28	0.22	0.11
262	3	2	1	2	1	0.79	0.82	0.76	0.04	532	5	5	1	3	1	0.26	0.28	0.23	0.09
263	3	2	2	2	1	0.64	0.69	0.6	0.06	533	5	5	2	3	1	0.21	0.23	0.19	0.1
264	3	2	3	2	1	0.5	0.55	0.46	0.09	534	5	5	3	3	1	0.16	0.18	0.14	0.12
265	3	3	1	2	0	0.99	1.03	0.94	0.04	535	5	6	1	3	0	0.31	0.35	0.28	0.11
266	3	3	2	2	0	0.8	0.86	0.75	0.07	536	5	6	2	3	0	0.26	0.29	0.22	0.12
267	3	3	3	2	0	0.63	0.69	0.57	0.09	537	5	6	3	3	0	0.2	0.23	0.17	0.13
268	3	3	1	2	1	0.65	0.68	0.62	0.04	538	5	6	1	3	1	0.21	0.23	0.18	0.11
269	3	3	2	2	1	0.53	0.57	0.49	0.07	539	5	6	2	3	1	0.17	0.19	0.15	0.12
270	3	3	3	2	1	0.41	0.46	0.38	0.09	540	5	6	3	3	1	0.13	0.15	0.11	0.13

Appendix B. Data Development and Research Notes

Introduction
Manifold, GIS software was used for data processing and visualization. Scripting or programming may be more efficient if similar data analysis is to be done on a regular basis. The mapping could be done in ArcGIS or another GIS program, but because PMG staff was more familiar with Manifold, processing, especially the table manipulation, was found to be easier. ArcGIS was occasionally used for processes found difficult in Manifold. See "Materials and Methods" for software and hardware references.

Cleaned data
The treatment data was gathered using the "smart" spray wands (SSWs) and stored on a miniSD card in .csv form. The .csv data was formatted as follows: Flow to number- 6 decimal places, Long/Lat to 8 decimal places, and DateTime data to include seconds (:SS). Obvious bad long/lat data was removed.

Inputted and checked data
Land cover and weed visibility data was inputted from work orders. The data was checked to ensure that the OPERATOR was consistent with the UNIT (SSW) used.

Obtained DEMs of area
Digital elevation models (DEMS) were obtained from the following sites:
Utah DEMs: http://gis.utah.gov/data/elevation-terrain-data/10-30-90-meter-elevation-models-usgs-dems/
Clicked on Download- 10 meter DEMs Interactive Map,
DEMs of Idaho and other states: http://viewer.nationalmap.gov/viewer/
This site does not produce .dem formats which were unable to import directly into Manifold. ArcGIS was used to projected it and export it as a .tiff file, which could be used in Manifold.

Purchased Surface Tools add-on found at
http://www.manifold.net/info/surface_tools.shtml , clipped DEM to area, and created slope raster.

Clipped raster area by polygon shape
Clip raster area by polygon shape. http://www.georeference.org/forum/t24769 Right clicked on the raster tab in the map, and then selected "Transfer selection".

Grid area to DEM
Created a drawing called 'Grid' and put it in map. This created an object in the 'Grid' drawing. Then ensured that it was active (on top), and used a View-Grid to create a grid. The lat/long was set to area. To avoid having to manually enter the X/Y of each area, the

desired area was adjusted into the screen, then 'Suggest' was clicked. This put the X/Y in automatically. The DEM areas were approximately 11.95 meters square so this measure was used in 'Spacing' with the 'Same spacing' checked (to make grid square). 'Create' was then clicked.

Adjust areas to DEM
The grid did not coincide exactly to the DEM. To adjust the grid to the DEM, Transform-Move Horizontally/ Move Vertically was used.

Grid to polygon areas
Transform- Bounded Areas was used to change grid to polygon areas.

Clipped areas to treatment areas
Transform-Clip was used to clip areas by treatment area boundaries.

Created centroids
Centroids were created to ensure the slope of the desired polygon was being used. The grids did not fit exactly to the DEM. If slope was transferred directly to the area polygons, some averages would be made because of overlap on area perimeters. Centroids were created using Transform- Centroids>Inner). "Inner" was used because the centroid was being created from a polygon.

Transferred slope data to centroids then to area polygons
The slope was transferred from a raster to centroid points using Drawing-Transfer Heights (see: http://www.georeference.org/doc/drawing_transfer_heights.htm). On the column, Transfer Rules > Copy was used to transfer the slope from points to areas using Spatial Overlay.

Calculated Up/Down travel and TimeChange
The .csv table was exported from Manifold into Excel. The data was sorted first by Operator number then by DateTime. The Up/Down Travel elevation difference (distance in ft.) was calculated by subtracting previous elevation from current elevation. Time Change was calculated by subtracting previous DateTime from current DateTime and multiply by 86400 (number of seconds in a day) http://www.ozgrid.com/forum/showthread.php?t=95702. The two columns were copied and pasted special to make data permanent. Unrealistic UpDnTravel points were removed (>40 ft.).

Data was sorted by TimeChange and any data less than 0 and greater than 4 seconds was removed (1189 of 37891 (3.1%) data points at one site, and 994 of 8838 (11.2%) in another site). This was data that skips to another treatment date or had equipment errors.

Formats were corrected (especially flow and DateTime) then data was re-imported to Manifold. The sort was re-run so that the data will be renumbered in a format that was easy to use.

Created line paths from points

A script was written that made a line from points. The lines can be separate by operator or days:
https://confluence.cornell.edu/display/GIS/Create+multiple+track+lines+from+a+set+of+points+%28Manifold%29

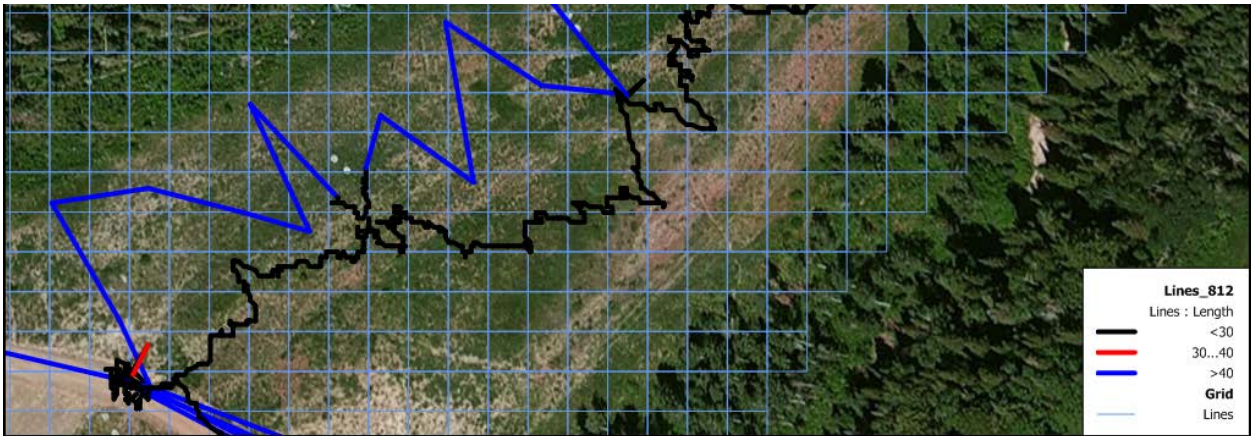
```
--Multi-track
SELECT
   [OPERATOR],
   ConvertToLine(AllCoords([temp]))
FROM
   (SELECT [OPERATOR], [Geom (I)] AS [temp]
    FROM [Site_1]
    ORDER BY [DATETIME]
   )
GROUP BY [OPERATOR]
```

Made multi-tracks

Multi-tracks were copied, and then 'copy' was used for Transfer Rules to copy OPERATOR to all new line (path) segments. Transform with Explode was used to break paths into line segments. A column for line segment lengths was created by clicking column heading, then Add- Active Column followed by using the script:

```
Function Func
        Func = Record.Data("Length (I)")
End Function
```

Lines over 30 ft. long were thrown out, otherwise after the next steps lines would be left over from extensions between treatment areas. GPS errors were unrealistic compared with theoretical travel speed (see map below).



Created line Grid from Area
Grid was created by using Transform- Boundaries

Cut line to grid
Grid was copied and overlaid to line drawing. A selection was created using Selections window called ‘grid’. Edit-Select Inverse was used to create new selection called ‘line.’ Transform- Intersect Lines was used to clip lines at the grid boarder using ‘all objects’. Selections window was then used to select and delete ‘grid’.

Calculated travel path lengths
An active column was added by right clicking on column heading. Script was inserted, then a right click on the column heading was used to display and select Recompute then Flatten to calculate path lengths and make column permanent. Ensure line drawing is projected or it will be in lat/long and give distance in degrees instead of feet.

Added sum of path length to areas
The sums of path lengths were summed to areas using Spatial Overlay. “Sum” was used in Transfer Rules. Data less than 20 feet was thrown out because it represented only a partial transect across an area. The maximum theoretical distance at 5 ft swath x 6 swaths to cover the area is 6 x 30 ft. =180 ft. Any areas with path sums > 180 ft. were removed.

Summed point data to polygon areas
Summed and transferred point data to polygon areas using Spatial Join. The number of flow points in each square polygon was summed as follows:
A ‘FlowPoints’ field was added to the point table. Flow >0 was defined as ‘1’ and 0 flow data was defined as ‘0’. The Spatial Overlay was used to add the points in an area using the Transfer Rule as ‘sum’.

The following transfer rules were used in the columns:

Slope- not transfer, Length- not transfer, PLANTID- max, Operator- copy, Flow- sum, Sweep- ave, Long- ave, Lat- ave, GPSSpeed- ave, Elevation-ave, DateTime-min, Unit-copy, Terrain- min, Visibility- min, UpDnTravel- sum, TimeChange- sum, Count-sum.

Note: For 'not transfer' turn off the ' transfers' by un-clicking the "Transfer column" check box in 'Column Transfer Rules'.

Changed labels:
Some of the column names were changed: Flow-FlowTotal, and GPSSpeed-GPSSpeedAve.

Calculated treatment time in Acres per Hour:
Travel time per area in seconds was calculated by dividing Length of lines traveled by average speed in feet per seconds. This was changed to hours by dividing it by seconds per hour.

```
Function Func
Func=(Record.Data("Area (I)")/43560)/ ((Record.Data("LengthFeet")/(
Record.Data("GPSSpeedAve")*1.46667))/3600)
End Function
```

AcresPerHour zeros and those greater than theoretical treatment max of 5 mph and visibility of 80 ft. (approx. 60 Acres Per Hour) were thrown out.

Created time in columns
http://www.pctools.com/guides/scripting/id/23/?act=reference
DATETIME manipulation:
Weekday name was obtained from the DATETIME get Weekday() (a number).
WeekdayName() was then used to get a name from the number (Monday, Tuesday, etc.)
or Mon = WeekdayName (Weekday (Record.Data("DATETIME")))
Month was obtained: Mon = MonthName(Month(Record.Data("DATETIME")))
Hour was obtained: HourPeriod = Hour(Record.Data("DATETIME"))
http://www.pctools.com/guides/scripting/id/23/?act=reference
Columns are flattened as they were created to make them permanent.

Exported and cleaned table
Cleaned Data:

ID	Site	AcresPerHr	GPSSpeedAve	TimeChange	LengthFeet	FlowTotal	FlowPoints	PLANTID
1890412	CC	4.35	0.04	59	20.1	0.001298	1	
1890243	CC	0.15	1.26	7	20.46	0.00352	3	
1890141	CC	0.07	2.79	5	20.87	0	0	
1890240	CC	0.39	0.5	26	20.96	0.01061	9	Hounds Tongue
1890461	CC	0.2	1.01	5	21.08	0	0	Hoary Cress
1890197	CC	0.59	0.34	22	21.16	0.002558	4	
1890379	CC	0.25	0.81	20	21.29	0.00087	1	
1890351	CC	0.09	2.11	5	21.31	0	0	
1890462	CC	0.15	1.35	20	21.35	0.004394	7	Hoary Cress
1890402	CC	2.78	0.07	228	21.4	0.048638	42	Myrtle Spurge
1889991	CC	0.31	0.66	19	21.85	0.0132	9	Hounds Tongue

TERRAIN	VISIBILITY	Slope	UpDnTravel	OPERATOR	UNIT	Month	Hour	Weekday	ELEVATION
1	3	21	0.33	5	1303	June	10	Tuesday	5557.05
1	3	32	-1.31	8	1304	June	11	Tuesday	5453.55
1	3	9	0.66	8	1304	June	14	Tuesday	5426.77
1	3	27	5.58	7	1305	June	14	Tuesday	5331.01
1	3	38	0	7	1305	June	12	Tuesday	5790.81
1	2	4	4.59	8	1304	August	8	Tuesday	5506.86
3	3	30	5.57	8	1304	June	9	Tuesday	5378.96
1	2	27	3.28	8	1304	August	7	Tuesday	5353.94
2	3	26	-0.66	8	1304	June	12	Tuesday	5792.92
1	3	18	4.93	7	1305	June	9	Tuesday	5448.37
1	2	27	-3.29	5	1303	May	14	Thursday	5255.84

Terrain=Land Cover

CURRICULUM VITAE

Bryan E. Dayton
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EDUCATION

2011-2014 PhD, Plant Science-Ecology, Utah State University
Dissertation: Introducing Two New Weed Control Tools: A "Smart" Spray Wand and a Wildland Weed Treatment Time Model
Advisor: Dr. Ralph E. Whitesides

2000-2002 M.S., Plant Science, Utah State University
Thesis: The Effect of Hydration on Stratification Efficiency of Peach and Apple Seeds
Advisor: Schuyler D. Seeley

1987-1992 B.S., Therapeutic Recreation, minor: Family Science, Brigham Young University

F**ELLOWSHIP**

2011-present PhD research funded by private business: PMG Environmental ($20,000/yr)

WORK EXPERIENCE

2009-present **Program Manager and R&D**, PMG Environmental, Richmond, Utah

- Monitor herbicide use and weed response using geospatial (GIS) data
- Research weed treatment cost modeling in cooperation with Utah State University
- Research and develop data flow for business accountability and client information
- Train and educate staff
- Plan and coordinate effective weed treatment with clients and staff
- GIS mapping and treatment reports for clients

2008 **Forage development specialist**, Island Dairy, O'okala, Hawaii

- Established field corn and pasture trials in coordination with the corn breeder and extension specialists at the University of Hawaii at Hilo
- Coordinated crop and forage management with the dairy owner and farm laborers
- Operated equipment and coordinated maintenance and repairs

2003-2008 **Plant breeding associate**, Improving Perennial Plants for Food and Bio-Energy, Inc. (IPPFBE, Inc), Richmond, Utah

- Researched, wrote and implemented breeding plans
- Established and maintained plants in the field and greenhouse
- Controlled pests and weeds
- Evaluated trials, maintained records and database, and reported findings to the board and national organization
- Wrote grants and organized community outreach in schools and with extension educators
- Initiated cooperative projects with extension professionals and community farm producers

TEACHING

2001-2002 **Fruit Production Lab Instructor**, Plant Science, Utah State University

- Taught plant and fruit anatomy, spray scheduling, pruning, propagation, and insect, disease and weed control.

MANUSCRIPTS IN PROGRESS

Dayton, B. E., R. E. Whitesides, and S. Pratt. 2014. Precision accountability in wildland weed treatment using a “smart” spray wand to combine precision treatment and mapping.

Dayton, B. E., R. E. Whitesides, and S. Pratt, 2014. Utilizing a “smart” spray wand to develop a backpack herbicide treatment cost calculation model.

POSTER SESSIONS

Dayton, B. E., R. E. Whitesides, and S. Pratt, 2014. “Smart” spray wand use in development of herbicide treatment cost calculation model. Western Society of Weed Science meeting. Colorado Springs, Colorado. March 10-13.

Dayton, B. E., R. E. Whitesides, and S. Pratt, 2013. A cost calculation model for estimating backpack herbicide treatment using a smart wand, slope, weed canopy cover, weed visibility and terrain. Western Society of Weed Science meeting. San Diego, California. March 11-14.

GRANTS

Dayton, B. E and C. Reed Funk, Utah Nut Tree Rootstock and Cultivar Trial, Utah Specialty Crop Block Grant, 2007-2008. $18,000.

Haggarty, J., D. Drost and **B. E. Dayton**, Commercial Artichokes in the Intermountain West, Western SARE, 2006-2007. $5180.

PROFESSIONAL ORGANIZATIONS AND SERVICE

Western Society of Weed Science, member
Utah Horticulture Association, member
Utah Weed Control Association, member
Northern Nut Growers Association, Cultivar Inventory chairman